

The Wi-Fi Alliance
Spectrum & Regulatory Committee
Spectrum Sharing Task Group
Regulatory Task Group

**Spectrum Sharing in the 5 GHz Band
DFS Best Practices**

October 10, 2007

Wi-Fi Alliance
Spectrum & Regulatory Committee

Creation and maintenance of this document

This document was created by wireless LAN experts of the Wi-Fi Alliance Spectrum & Regulatory Committee, the IEEE 802.18 Radio Regulatory Technical Advisory Group.

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As radar and wireless LAN technology evolve, this document will be updated as and when required.

Contributor	Company
Jan Kruys	Cisco Systems
Edgard Vangeel	Cisco Systems
Bruce Kraemer	Marvell Semiconductor
Vijay Auluck	Intel Corporation
Rich Kennedy	OakTree Wireless/ETS-Lindgren
Jim Raab	OakTree Wireless/Dell Computer Corporation
Rob Kubik	Motorola

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1 Introduction

Due to the scarcity of radio frequency spectrum, many radio systems have to share spectrum with other radio systems – in one form or another; wireless LANs (also known as radio LANs, or RLANs) are no exception. Wireless LANs are allowed to operate in the 5 GHz bands which are also used by many radar systems.

This whitepaper is intended to help the designers of wireless LANs that operate in the 5 GHz frequencies understand the requirements for radar detection and avoidance - also known as DFS or Dynamic Frequency Selection.

This document deals only with the regulatory requirements and the philosophy under which they were issued. It does not provide design rules or example implementations. By avoiding such “blueprint” material, innovation among wireless LAN designers is maintained and encouraged.

2 Purpose of this document

DFS is a cornerstone of the world-wide 5 GHz frequency allocation to wireless LANs because it allows wireless LANs to share these frequencies with various radar systems. DFS assures that the wireless LANs do not cause interference to the radar systems. However, the ITU Recommendation on DFS and its derivatives only provide detection threshold criteria and they give test patterns to test DFS implementations. Therefore, a DFS design that is able to meet all the test criteria is not necessarily a good design that will be able to deal with the various radars in the real world.

The interaction between radar systems and wireless LANs is complex and the variation in radar designs considerable. In order for DFS to be effective, it must be designed with a good understanding of these complexities and variations. This document aims to facilitate that understanding and to help, indirectly assure that DFS designs meet their main purpose: effective detection and avoidance of radar systems.

3 The importance of Spectrum Sharing

Spectrum sharing is rapidly becoming the solution to the increasing demands for bandwidth of many different applications. In the case of wireless LANs, the initial air interfaces used unlicensed spectrum in the 915 MHz and 2.4 GHz bands – in which all kinds of devices are allowed to operate – including industrial, scientific and medical systems.

As wireless LANs developed into a major communications technology, more spectrum became necessary. Regulators world-wide stepped up to that challenge and after a long period of preparation, they agreed to allow wireless LANs to operate in the 5 GHz band – sharing with terrestrial radar systems.

This is only one example of how demand for spectrum was met by allowing two different systems to share a frequency range - RLANs and radar systems - based on a well defined assessment of interference issues and a specification of requirements that would remove all or most of the actual interference. Other sharing regimes are being developed, e.g. for the 2.5 GHz band, the 3.4-3.8 GHz band and for the 5.8 GHz band. In the future this list is expected to grow.

Essential to the success of sharing spectrum now and in future is that the deployed systems do meet the technical requirements for sharing. In some cases these requirements

include the detection of other, primary, spectrum users and avoiding co-channel operation; in other cases it means listening to and acting upon enabling signals that are emitted by or on behalf of primary spectrum users.

Failure of the sharing regime in a given band has potentially severe ramifications. The vendor that puts such equipment on the market may be fined or have his market access restricted. More serious would be that primary users attempt to rescind the sharing rules, citing the failure of the sharing regime as the reason. Regulators will be put in a very difficult position to keep the sharing regime in place against the political and/or economic pressures created by primary users.

With the above in mind, it will be clear that the DFS based sharing regime developed for the 5 GHz band has to succeed. Its success depends primarily on the quality of the DFS implementations that are brought to market. This document is intended to help designers of DFS based equipment, to achieve that level of quality.

4 A short history of “DFS”

4.1 Europe Spawns the Idea

In 1999, the CEPT published ERC Decision (99)23 on the harmonized frequency bands to be designated for the introduction of High Performance Radio Local Area Networks (HIPERLANs). In total 455 MHz of spectrum was allocated to these Hiperlans under more or less similar conditions (power levels, DFS, TPC) as later on agreed during WRC03. Devices operating in the band 5150-5350 MHz were restricted to indoor use only and were limited to 200 mW EIRP. Outdoor operation was limited to 5470 – 5725 MHz but they could use power levels up to 1 W EIRP. DFS and TPC were required when operating in 5250-5350 MHz or 5470-5725 MHz.

In the mean time ETSI had started the development of a Harmonised Standard that included the first DFS conformance specification ever developed. Initially, the standard was drafted specifically for Hiperlan. That approach was changed in light of the success of the IEEE 802.11 technologies, and finally in June 2003, Europe sent the first version of the technology neutral standard, EN 301 893, into national voting just prior to the start of the WRC03.

4.2 WRC03 - ITU-R Resolution 229

In 2003, after a preparation of many years, the International Telecommunications Union (ITU), at its World Radio Conference 2003 (WRC03), agreed on a new frequency allocation on a co-primary for RLAN systems. This spectrum, a total on 455 MHz spread over the 5150-5350 and 5470-5725 MHz bands¹, was allocated on a non-interfering basis to “Wireless Access Systems including RLANs”. This means that wireless LAN have to protect with incumbent systems; primarily weather radars, satellite radars, and military radars. In order to eliminate potential RLAN interference to the radar systems, a Dynamic Frequency Selection (DFS) mechanism was introduced in the ITU proceedings. This mechanism is

¹ The band in between is allocated to airborne radar systems.

assumed to detect radar emissions and to assure that wireless LANs do not operate on channels on which nearby radars are operating.

4.3 Recommendation ITU-R M.1652

Per ITU-R Recommendation M.1652², DFS is required in the 5250-5350 MHz and 5470-5725 MHz bands. Depending upon the national jurisdiction, radars may operate anywhere within these bands. Specific radar operating frequencies are dependent upon a variety of factors, including types of weather, latitude of operation, and target detection requirements.

4.4 US DFS History

In 2000, as the RLAN industry in North America was preparing to enter the 5 GHz spectrum market with products designed to the IEEE 802.11a standard, manufacturers with worldwide distribution were concerned that Europe would restrict this band to HiperLAN (High Performance Radio LAN) products as specified in ERC Decision (99)23. HiperLAN is a specific RLAN technology developed by ETSI. The ERC Decision (99)23 mandated two mechanisms to protect radars and other primary users of this band: DFS (Dynamic Frequency Selection) and TPC (Transmit Power Control). As a result, a project (P802.11 TGh) was started to add these mechanisms, with the assumption that if these additional regulatory requirements were met, global adoption of 802.11a would be possible.

At the time the 5 GHz band for RLANs in the US was restricted to the 5150 – 5250 MHz, 5250 – 5350 MHz and 5725 – 5825 MHz bands, but planning was already in the works for the 2003 meeting of the World Radiocommunication Conference, to add the 5470 – 5725 MHz band. This made DFS even more important for the North American market. Over the course of the next three years, the FCC, with the help of the wireless LAN industry and the NTIA, developed the DFS rules for the US.

4.5 Industry Involvement

The spectrum used within US Federal agencies is administered by an Executive Branch organization known as the NTIA (National Telecommunications and Information Administration). Spectrum allocated for use by US commercial and private citizens is administered by the FCC (Federal Communications Commission).

When considering opening the 5 GHz band for use by WLANS, the NTIA expressed a strong desire that products entering the new band would adequately protect US military radars. This desire informed the US position at the WRC-03 which developed the first DFS requirements document – ITU-R Recommendation M.1652.

The Broadband Radio Access Networks (BRAN) group in ETSI developed the first 5 GHz Harmonised Standard (EN 301 893). The DFS test specification included in this standard became the basis for the development of the FCC DFS test specification and other test specifications in other countries.

In the US, the FCC, NTIA and the wireless LAN industry collaborated to develop an extended set of DFS equipment test specifications that would assure compliant equipment

² <http://www.itu.int/rec/R-REC-M.1652/en>

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would provide protection of some key radar systems not previously addressed by the ITU-R Recommendation M.1652. The new requirements and the related radio certification³ process were released in July of 2006.

In parallel, the French military imposed similar extensions on the radar detection requirements that were incorporated by ETSI into version 1.3.1 of the EN 301 893 standard which addresses compliance criteria for 5 GHz wireless LANs in Europe.

4.6 IEEE Channel Assignments

The fifteen specific IEEE-defined, 20 MHz-wide wireless LAN channels and the equivalent frequencies are outlined in Table 1 below, as determined by the formula $f_c = 5000 \text{ MHz} + (5 \times \text{channel number})$.

5250-5350MHz		5470-5725MHz	
Channel	Freq (MHz)	Channel	Freq (MHz)
52	5250-5270	100	5490-5510
56	5270-5290	104	5510-5530
60	5290-5310	108	5530-5550
64	5310-5330	112	5550-5570
		116	5570-5590
		120	5590-5610
		124	5610-5630
		128	5630-5650
		132	5650-5670
		136	5670-5690
		140	5690-5710

Table 1: IEEE 802.11 wireless LAN channel numbers and frequencies

³ http://fjallfoss.fcc.gov/edocs_public/attachmatch/FCC-06-96A1.doc

5 Regulatory Requirements

5.1 ITU-R Resolution 229 & ITU-R Recommendation M.1652

At the ITU's World Radio Conference of 2003 it was decided, through ITU-R Resolution 229, to allocate the spectrum between 5150 and 5350 MHz and between 5470 and 5725 MHz on a co-primary basis to "Wireless Access Systems including RLANs" under the proviso that RLANs should avoid interference into the other primary users – radar systems deployed on satellites, and on the ground, including mobile and maritime radars. Avoiding such interference into surface radars was considered possible if RLANs would implement a mechanism to detect and avoid causing co-channel interference with these radars: this mechanism is called DFS – Dynamic Frequency Selection. Its purpose and performance criteria were defined by a separate Recommendation: M.1652.

The objective of DFS as described in ITU-R Recommendation M. 1652⁴ is to avoid interference from RLANs into radars. This document specifies the DFS detection and performance requirements but does not specify how DFS is to be implemented. However, it does define test procedures for validating DFS detection and performance

5.2 Europe

5.2.1 Regulation

As given already in clause 4.1, after the WRC03, the CEPT (46 member countries) had revised the existing ERC decision (99)23 resulting in the 'ECC Decision (04)08 on the harmonised use of the 5 GHz frequency bands for the implementation of Wireless Access Systems including Radio Local Area Networks'.

By mid of 2005, the European Commission published Commission Decision 2005/513/EC by which all EU member states (currently 27) had to open the 5 GHz bands by 31 October 2005. The requirements contained in the Commission Decision are identical to those contained in ECC Dec(04)08.

It should be noted that the regulation clearly specifies that radars need to be protected.

5.2.2 R&TTE Directive (Radio & Terminal Telecommunications Equipment)

The placing on the market of radio equipment within the EU is regulated by the Directive 1999/5/EC (R&TTE Directive)⁵. This Directive replaces the national Type Approval regimes by a Market Surveillance regime. The European Commission has mandated ETSI to develop the so called Harmonised Standards for radio equipment. According to the R&TTE Directive, compliance with a Harmonised Standard will allow the manufacturer to 'presume' compliance with the essential requirements of the Directive 1999/5/EC and as such he is allowed to place his product on the community market. Individual member states can not object to that as the burden of proof for non-compliance is on them.

⁴ <http://www.itu.int/rec/R-REC-M.1652/en>

⁵ <http://ec.europa.eu/enterprise/rtte/dir99-5.htm>

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Member states can challenge either the conformance of individual products (article 9.1 & 9.2 of the R&TTE Directive) and take appropriate action against the manufacturer or can even challenge the harmonized standard itself if they consider that the standard does not ensure compliance with the essential requirements of the directive. This is described in article 5.2 of the R&TTE Directive.

More information on the R&TTE Directive is available from the web pages from the European Commission on http://ec.europa.eu/enterprise/rtte/index_en.htm

5.2.3 Harmonised Standard EN 301 893

Compliance with a Harmonised Standard allows the manufacturer to place his product on the community market, however it might not be sufficient to allow him also to use the equipment. The regulation specifies that radars need to be protected, but being capable of detecting any of the radar test signals included in Table D.4 of EN 301 893 does not mean your device can detect any deployed radar. The final responsibility remains with the manufacturer, he can not hide behind the compliance with a harmonised standard if his product is unable to detect certain radars.

The first version of EN 301 893, version 1.2.3, was published by ETSI in August 2003. That standard had only 3 radar test signals although reference was made to ITU-R Recommendation M.1652.

Member states found equipment on the market that could only detect the 3 radar signals but not other signals. These equipments are examples of equipment that is compliant with the standard but not with the regulation. Nevertheless it was decided to remedy this situation and as such version 1.3.1 was produced and published in August 2005. Compared to the first version, version 1.3.1 does include a wide range of radar test signals with Pulse Widths between 1 and 30 μ Sec and PRF rates between 200 and 4000 Hz.

In the mean time version 1.4.1 has been published. This was done to address an urgent need from industry to have a harmonised standard that also covers MIMO or other high throughput technologies and/or channel bonding.

By the end of 2006, regulators had reported the first interference cases (RLAN interference into weather radars) due to the fact that the DFS mechanism was disabled by the user or the operator of the network. Version 1.4.1 of the standard now also includes the requirement that the user shall have no access to any of the DFS settings. It has been made clear by the European Commission and individual regulators that it should not be possible to disable DFS.

5.3 US

5.3.1 Regulation

The FCC issued a Notice of Proposed Rulemaking (NPRM FCC 03-110) in May of 2003 requiring DFS and TPC to operate a wireless LAN in the 5470 – 5725 MHz band in the US, and added them also as a requirement in the 5250 – 5350 MHz band. This was followed in November with the Report and Order (FCC 03-287) requiring DFS testing, but leaving the test parameters unspecified. It was not until June 2006 that a final set of DFS test parameters, finally agreed to by the NTIA, were released with Memorandum and Order FCC 06-96, formally opening the 5470 – 5725 MHz band in the US.

5.3.2 FCC Part 15.407

The US DFS rules reside in 47 CFR Part 15, subpart E (15.407)- Unlicensed National Information Infrastructure Devices (<http://www.fcc.gov/searchtools.html#rules>). They are closely aligned with the ETSI rules with some variations in the radar test patterns (see FCC-06-96).

5.4 Other regions

Other regions have adopted regulations and conformance standards similar to either those applicable in Europe or in the US.

5.5 Regulation and Compliance

The ITU-R Recommendation M.1652 and its derivatives like the 47 CFR Part 15, subpart E and EN 301-893, describes the simulated radar signals and the procedures for validating the operation of DFS. The simulated radars signals correspond to a variety of real radar systems but obviously, not all radar signals are represented. Therefore, if a DFS implementation is able to detect all the radar signals specified in the EN, this gives confidence - but not proof - that the implementation will indeed perform adequately.

6 Types of Radars

6.1 Civilian navigation and maritime radars

These radars are found mostly on ships and along waterways where they are used to track and guide ships. Some of these radars are also employed by private companies and TV weather stations to track rain showers and storms.

Typically, these radars operate at short to medium range and power levels in the range of 10 to 50 kW. Pulse patterns are typically straightforward with a PRF that lies between 800 and 4000 pulses per second and a rotation speed of 10 rotations per minute.

6.2 Weather radars

Most weather radars use a pulse width between 0.8 μ Sec and 2 μ Sec, although a tendency has been noticed recently to use even shorter pulses, down to 0.5 μ Sec. The typical PRF used ranges from 250 Hz to 1200 Hz.

Weather radars use different pulse patterns, e.g. a fixed (constant) PRF, or a Single Pulse based PRF or Packet based Staggered PRF.

See clause 10 for more details of these different types of PRF.

Typical conducted power levels range from 100 to 250 kW and antenna gain can be up to 45 dBi. The 3 dB beamwidth (-3 dB beam angle = 1 degr). The rotation speed is between 1 and 6 rotations per minute.

Weather radars often operate according to a certain scanning scheme. Such a scheme consists of multiple helical scan patterns each of which can use a different pulse width and PRF. The total cycle time for a give scanning scheme can vary from 5 to 15 minutes. Depending on the type of radar, a scanning scheme may also include receive-only periods, often included in between 2 helical scan patterns. These are used for the noise calibration with the antenna pointing at 45 to 60 degrees elevation.

6.3 Military radars

In general fixed frequency military radars use techniques similar to weather radars. That also includes the usage of staggered PRFs.

Military radars include rotating search radars that scan volumes of space much like civilian navigation radars as well as sector scanning radars and tracking radars.

In addition to fixed frequency operation, military radars often use frequency hopping techniques designed to avoid detection and interference. Some combinations of PRF, and hopping rate and rotation rate make detection by DFS a challenge.

Due to national security considerations, the details of military radars are classified and therefore; specifics can not be given here. Some publicly available information is contained in ITU-R Recommendation M 1638.

6.4 Evolution of radar technology

Radar technology continues to evolve as new (digital) techniques of pulse generation and receiver processing become available. Some of these trends can be seen in the emergence of shorter pulse widths, pulse compression (chirping) and more complex pulse patterns, all designed increase the radar's performance and resolution capabilities.

Therefore, coordination between radar community and the wireless industry is required to assure continued protection of radar systems as radar and wireless technology evolve.

Additional information about radar types, applications and their applications and characteristics might be found at various internet sites. [6]

7 RLAN Interference into Radar systems

7.1 Introduction

Radar is an acronym for RAdio Detection And Ranging. Radar stations may be fixed or mobile, and some are mounted on ships. Mobile radars are often military.

A radar system transmits a powerful set of narrow pulses into the environment. When these pulses strike an object, their energy is scattered and a small amount of that energy is bounced back towards the transmitting station. The radar's receiver then measures the time difference and the frequency shift information to calculate distance and other information about the object it struck.

Wireless LANs operating in the 5 GHz bands in the vicinity of radar systems can cause interference into the radar receivers if interference mitigation techniques such as DFS are not utilized. Because the RLAN energy is unrelated in time, frequency and phase, the RLAN signals look like powerful noise sources.

Because of the very high gain of the typical radar antenna, only very little Wireless LAN energy is needed to cause interference to radar systems. Therefore wireless LANs (without DFS) will cause interference not only when they are operating on the same frequency as the victim radar and the radar antenna points at the wireless LAN, but also when the wireless LAN is nearby and seen by the sidelobes of the radar antenna.

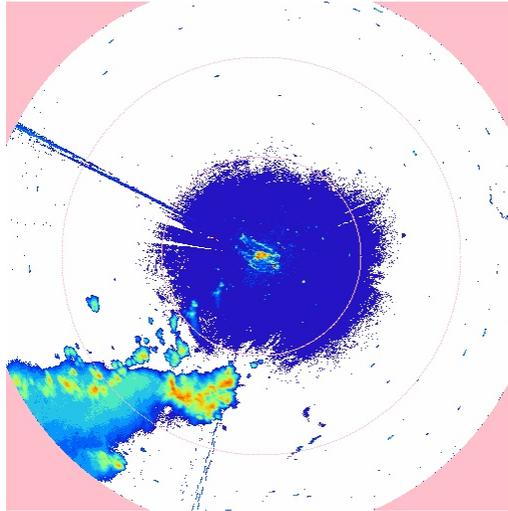


Figure 1: Wireless LAN interference into the radar's main beam

Since radar systems determine range information by measuring the time difference between a transmitted burst and the returned echo, any non-synchronized signal will effectively show a return on a radar screen, that, in case of large packets being transmitted by the wireless LAN, show up at all distances. In the latter case, the radar display would then show a continuous streak or stripe originating at the radar transmitter and extending to the radar horizon when DFS measures are not used. See figure 1.

If an RLAN is very close it may cause interference through the sidelobes of a radar. In that case, the picture looks like Figure 2:

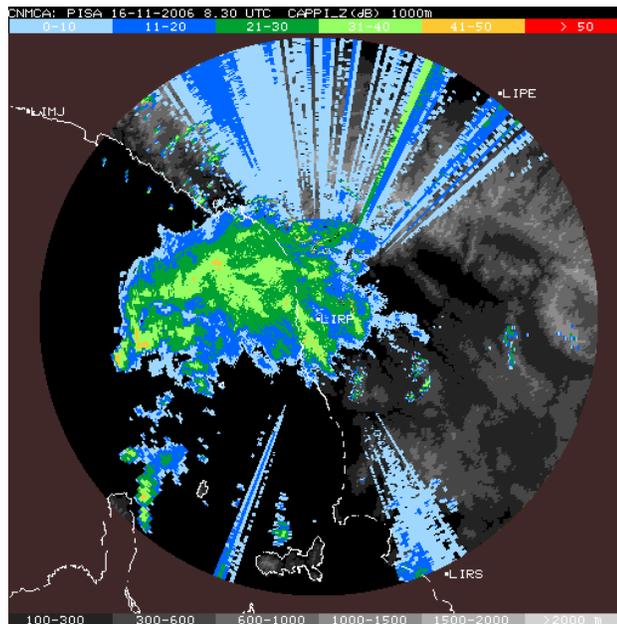


Figure 2: Wireless LAN interference into the radar antenna sidelobes

8 Radar Detection & Response - DFS Requirements

8.1 Introduction

The DFS requirements can be split in two parts: the detection criteria and the “response criteria”. The former specify the RF power and signal timings of radar signal that the wireless LANs must be able to recognize. The latter describe what the wireless LAN is required to do in response to a detection event.

The detection requirements are based on studies and simulations that showed that for wireless LAN operating at 200 mW radiated power or less, detection of radar signals of -62 dBm or higher was sufficient. For higher power wireless LAN this value is -64 dBm. These values are well above the noise floor of the typical wireless LAN receiver. In addition, ITU-R Recommendation M.1652 and its ETSI and FCC derivatives specify a number of radar pulse widths and pulse interval ranges that should be used in the testing of a DFS implementation.

The response requirements describe what a wireless LAN is allowed to do before it has to leave the channel, on which it has detected a radar signal, completely. Within 10 seconds, the wireless LAN must cease all transmissions but during these 10 seconds it may continue to send some control information - for a total of 260 milliseconds. This allows wireless LAN devices to coordinate their changes from one channel to another channel. Once a radar has been detected in a given channel, the channel must be abandoned for 30 minutes which is known as the Non Occupancy Period (NOP).

How DFS Works

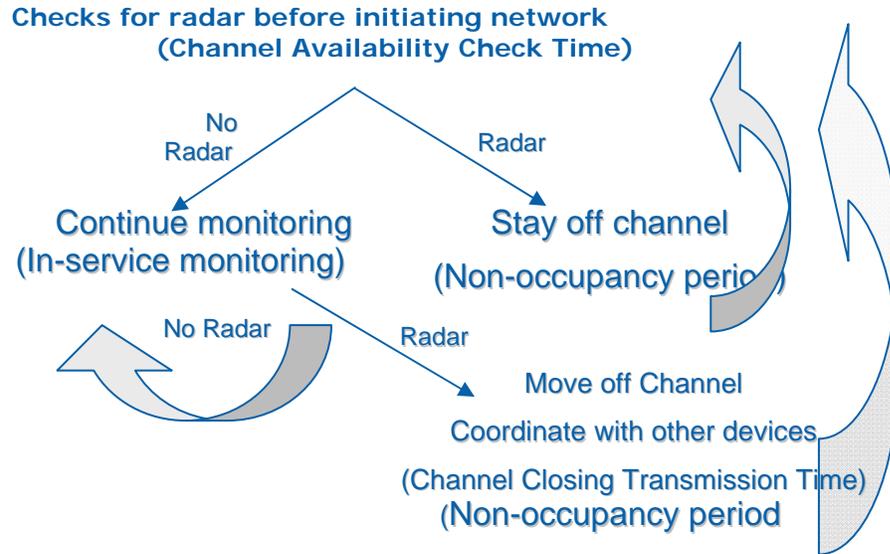


Figure 3: Schematic description of DFS

When choosing a new channel to operate on, a wireless LAN device must make sure that channel is not occupied by one or more radar systems. This is done through a channel availability check (CAC) for a minimum amount of time (minutes). Once operating on a channel the wireless LAN must continue to monitor that channel for radar pulses so that it will detect radars that come within its horizon or radars that are switch on while they are in the horizon of the wireless LAN. See figure 3.

For details of the DFS detection requirements, the reader is referred to Annex 1 which gives the data for the US, Europe and Japan.

The preceding gives an introduction to the DFS requirements. For the full details, readers are referred to ITU-R Recommendation M.1652 [4].

It should be noted that, as mentioned in ITU-R Recommendation M.1652, the ability of DFS to prevent interference rests on the large difference between the power output of a radar system and the low power output of the RLAN devices. If an RLAN detects a radar signal, it can cause interference to the radar. Vice versa: if the RLAN does not see a given radar, it will not cause interference into that radar.

8.2 Radar Recognition Requirements

As noted above, radar signals are typically very strong signals. The power amplifiers of a radar produce pulses in the range of a few tens to a few hundreds of kilowatts. These pulses are fed into an antenna system that focuses the pulse energy into a narrow beam. Typical

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antenna gains are in the order of 40 dBi. The result is a pulse power in the order of megawatts. In spite of a strong transmit pulse the return pulses are very weak. Hence, other energy generated in the same frequency band can be received by the radar at signal levels that can cause the radar to be unable to perform its intended function. As the same high gain antenna is used for transmitting and receiving, radar systems are very sensitive to interfering signals.

The frequencies occupied by the radar signal may be just a very narrow band – as in the case of certain weather radars, or they may occupy a wide range as in swept pulse (chirped) radars. In the latter the returned signal is un-swept to reduce the noise content and to improve the range precision. Yet other radars change their operating frequency according to some pattern in order to avoid detection and to improve noise performance. These radars are typically operated by the military.

Radar pulses travel in a straight line which means that buildings and other objects as well as the curvature of the earth produce radar “shadows” in which the radar signal is very weak. A radar beam creates a complex pattern of illuminated surfaces much like a search light produces a pattern of light and dark areas. The dark areas correspond to no illumination by the radar. Reflections of buildings and other structures may also cause partial lighting of shadows so the same radar device may appear visible from different directions

The figure below shows the radar horizon of an established (Canadian) weather radar. Distances are in miles. The shape of this “footprint” varies significantly with the elevation of the earth’s surface above the ideal curvature and with the distance from the radar location. RLANs within this footprint are will see the radar signals; outside the footprint they will only see it if they are (well) above earth’s surface.

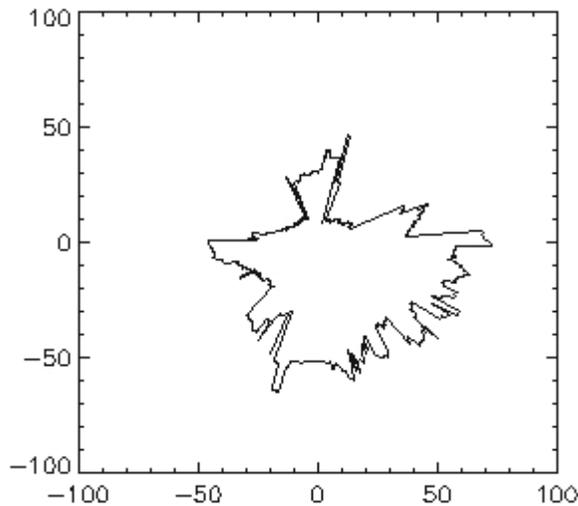


Figure 4: Radar footprint of a weather radar (distances in miles)

Since radars have narrow beams and since they typically follow a horizontal scanning or rotation patterns, the time that a beam is pointed in a given direction is short and the number of pulses seen by an RLAN is therefore limited by the combination of beam dwell time and the basic pulse repetition frequency of the radar system. See “[Types of Radars](#)” above.

Weather radars are used for measuring weather conditions at large distances. Typically, these radars implement a complex scan patterns that include helical scanning and probing storm spots. The result is that such a radar may be pointing away from a given (RLAN) location for up to 10 minutes. However, if the radar is close by – at less than a few miles – its antenna sidelobes may be visible to the RLAN. This may cause the same pulse train to be seen multiple times – or even continuously.

8.3 Radar detection considerations

The above sketches the background to the following discussion of radar detection issues.

8.3.1 Detection Thresholds – pulse width and power levels

Radar protection hinges on the ability of the RLANs to detect radar pulses. The main properties of these pulses are width and amplitude (power).

The minima for both are given by the currently applicable regulations: 1 μ sec and -62 dBm (-64 dBm for RLANs with > 200 mW EIRP). In the meantime, Japan has reduced the minimal pulse width to .5 μ sec. Canada operates radar with .8 μ Sec pulse width. Europe (ETSI) may adjust the lower limit in EN 301 893 from 1 μ Sec down to 0.8 μ Sec. Manufacturers must remain aware of the changes in regional requirements with regard to the minimum pulse width and other DFS parameters.

The maximum is set by the FCC’s requirement for detecting pulses up to 100 μ Sec wide. It should be noted that, notably with the introduction of MIMO technology, frame lengths drop well below 100 μ sec and therefore the DFS implementation has to distinguish between such long radar pulses are RLAN transmission frames.

The DFS detection threshold is defined with reference to a null gain antenna. If the antenna gain is x, the threshold should be set to $-(62-G)$ dBm (or $-(64-G)$ dBm, depending on the EIRP of the device.

8.3.2 Scan patterns

Radar systems employ scan patterns that vary depending on their application. Weather radars and some airport radars may scan through 360 degrees whereas an air defence system may look only at a sector (90 to 120 degr). Tracking radars typically lock-on to their targets and therefore the direction their antennas are pointing to changes slower compared to a rotating radar. Weather radars typically employ a scanning scheme (often called a scanning strategy) consisting multiple helical scan patterns and with a total cycle time of as much as 10 minutes.

These differences in scan patterns lead to different bursts and burst interval periods seen by a RLAN at a certain position with the radar’s footprint.

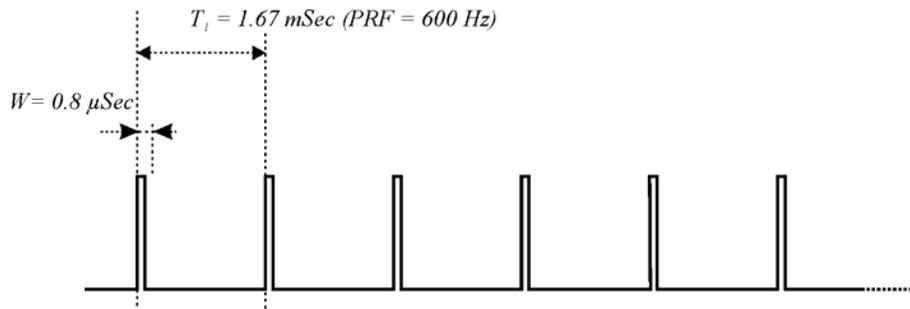
8.3.3 Pulse patterns

The typical “search” radar rotates regularly and as its beam sweeps over an object, that object is illuminated by a train of radar pulses. The pulse interval varies with the operating range of the radar: for 200 pps for long range radars to 4000 pps for short range radars.

It is quite possible that more than one radar may be visible to an RLAN on the same RLAN channel. If this happens the RLAN may see a variable pattern of pulses – some stronger than others - but as both radars will not be synchronised, there will be no time correlation between the pulse trains.

8.3.4 Constant PRF

Most radars operate with a constant PRF (Pulse Repetition Frequency). To increase the range resolution of some radars, a staggered or interleaved PRF is often used these days.



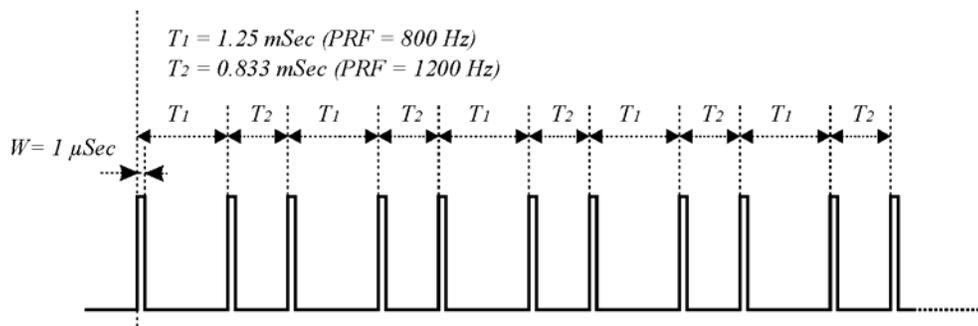
8.3.5 Staggered PRF

Interleaved or Staggered PRF operation is used to cope with multiple-time-around echoes. Far away targets appear as echoes of the following pulse at shorter range. It is possible to remove this range ambiguity by changing the time between pulses – which is equivalent to changing the PRF. With different PRFs, the target will appear at different ranges. Using a proper logic, it is possible for the radar to identify the echo as a second-time-around one, and assign to it the proper range. As a general rule, use of ‘n’ different PRFs allows to solve up to nth-time around echoes (normally, 3 or 4 are used).

It is possible to change the PRF at each transmitted pulse, but in modern radars using "packet" processing, they are changed on a packet basis (some tens of pulses).

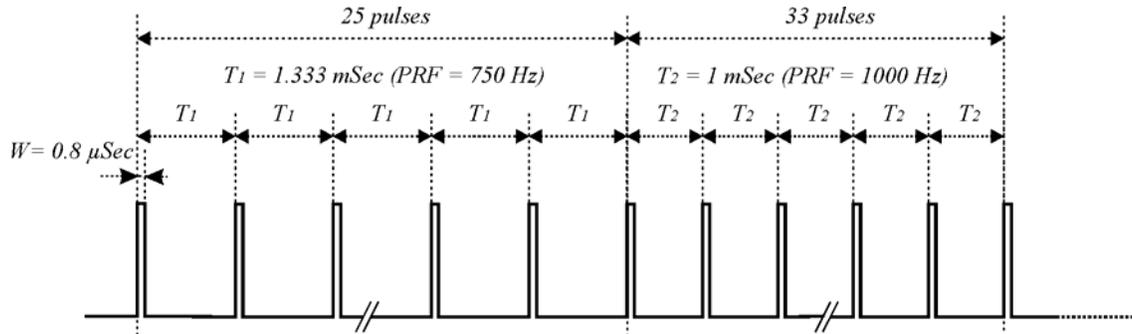
- **Interleaved/Staggered PRF – Single Pulse based.**

In this mode, the PRF changes every pulse. Most weather radars operating in this mode use 2 different PRIs (or PRFs). The French weather radars use 3 different PRI/PRF values.



- **Interleaved/Staggered PRF – Packet based.**

In this mode the PRF is not changed every pulse but is changed on a packet basis. European weather radars operating in this mode use 2 different PRFs.



Detection of Packet Based Staggered PRF is probably easier than detecting a Single Pulse based Staggered PRF which requires a proper DFS algorithm to be implemented.

8.3.6 Fixed Frequency versus Frequency Hopping

Weather radars are an example of radars that operate on a fixed frequency. In most regions, the band 5600 to 5650 MHz have been allocated to weather radars.

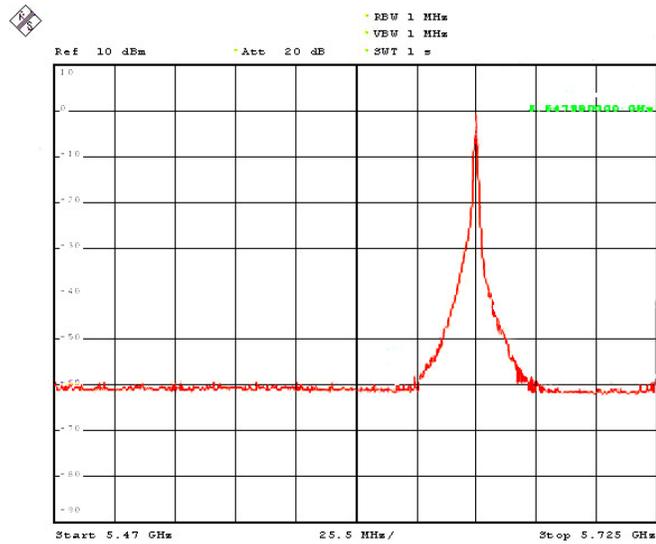
Some military radars use frequency hopping techniques. The combination of the hopping rate, the PRF, the antenna rotation speed and the antenna beamwidth, determines the number of pulses seen by the RLAN during 1 rotation of the antenna. Due to national security considerations, actual data on these radars is not available; the test patterns and detection criteria specified in the DFS test requirements are the only guidance available to DFS designers.

8.3.7 Radar RF bandwidth

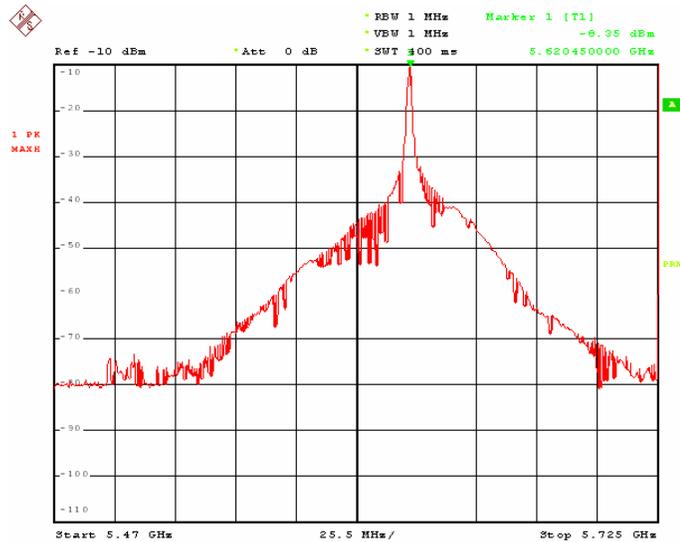
Radar transmitters use a variety of amplifier types, some produce a fairly clean output signal, some produce sidebands that can be as "little" as 40 dB down from the main emission level.

The picture below shows the emission of a weather radar with a fairly clean transmitter.

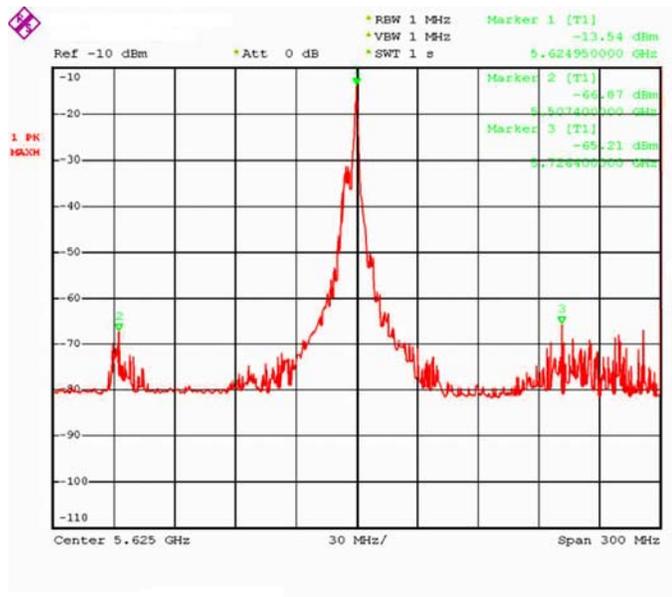
Wi-Fi Alliance
Spectrum & Regulatory Committee



Other transmitters may not be as clean as the example above and produce relatively high side lobes. Due to the high power levels and the high antenna gain of radar systems these sidebands may well exceed the DFS detection threshold, notably if the RLAN is relatively close to the radar – e.g. a few miles away. The implication is that an RLAN may see the same radar at different frequency channels. In the example below a single radar at a short distance away from the RLAN will trigger DFS on about half of the channels in the 5470 to 5725 MHz band.



Another symptom seen is that radar produce strong unwanted emissions at frequencies below and above the main signal.



9 RLAN Considerations

The variation in pulse patterns described above is compounded by the wireless LAN operating parameters such as channel bandwidth and channel occupancy and traffic patterns.

9.1 Channel bandwidth

The bandwidth of an RLAN affects the probability of interfering with a radar and it affects the probability of seeing a radar: the wider band would see more of a radar's emission – including its sidebands.

9.2 Traffic load

When an RLAN transceiver is transmitting, obviously the receiver is blocked and therefore the RLAN device is deaf to radar signals during transmission. This reduces the probability that a given radar pulse will be detected. Depending on the relative rates of RLAN frame transmissions, radar pulse width as well as the number of pulses in a radar burst (depending on antenna rotation speed), the probability of the RLAN detecting a given radar varies between 100% to less than a few percent. A good DFS design takes this into account – every pulse that is lost reduces the detection probability and therefore it reduces the ability of the device to detect radars and the ability of the device to meet the DFS requirements.

9.3 Channel Occupancy

In order to assure repeatable test procedures and results, the DFS test criteria include a defined level of traffic load to emulate a certain reference level of channel occupancy."

9.4 RLAN configurations

RLAN devices are typically deployed in networks of one form or another. Having each device implement and execute DFS procedure independently of all other devices in the network may lead to unstable network behavior that would severely affect the network users.

In order to facilitate implementation of DFS in networked devices, the regulations define two roles for RLAN devices: a “Master” role in which the device can initiate a network, and a “Slave” role in which the device cannot transmit without receiving an enabling signal from a Master. In addition, the EN 301-893 requires that devices that operate at more than 200 mW EIRP perform their own DFS detection and stop transmitting if it detects a radar signal.

Thanks to these role definitions, it is possible to delegate the DFS detection function to one or more devices within a network and to let these control the DFS response of that network. However, such a network must be small so that the master devices will see the same radars as the slave devices.

9.4.1 Access Point with Clients

Here the Access Point acts as the Master device and does the DFS (radar detection) on behalf of all the (associated) devices within its vicinity. The implications are that:

- a) If a client device loses connection to the access point, it may not use active scanning to associate itself again to this or to another access point unless it does its own radar detection. Passive scanning obviously is allowed as the client only listens in this mode.
- b) The communications between Access Point and clients has to be sufficiently fast to meet the requirement that the RLAN device may only transmit for a total of 260 msecs (Channel Closing Transmission Time) during a period of maximum 10 seconds (Channel Move Time) after detection of a radar signal. A relatively slow connection will leave the Access Point little time for coordinating channel changes with its clients.

9.4.2 Point to Point Links

Implementing DFS in point to point links calls for special care: the ends of the link may see different “radar landscapes” and therefore they have to operate their own radar detection independently of each other but can communicate to change to another channel in a coherent manner in case one of the devices detected a radar.

The above applies also if the endpoints use directional antennas.

9.4.3 Point to Multipoint Links and mesh networks

As described under 12.3 above, the devices involved may each see a different radar landscape and therefore each has to implement its own DFS function so as to assure it does not cause interference to nearby radar systems.

10 References

- [1] ETSI EN 301 893 V 1.3.1 (2005-08) Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering essential requirements of article 3.2 of the R&TTE Directive
- [2] ETSI EN 301 893 V 1.4.1 (2007-02) Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering essential requirements of article 3.2 of the R&TTE Directive [as of this revision date v1.4.1 is not yet released]
- [3] Title 47 of the Code of Federal Regulations 47CFR Part 15 (5-04-07) Subpart E – Unlicensed National Information Infrastructure (U-NII) Devices
- [4] [M.1652](http://www.itu.int/rec/R-REC-M.1652/en): 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
<http://www.itu.int/rec/R-REC-M.1652/en>
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