Dynamic Frequency Selection (DFS) and the 5GHz Unlicensed Band

by Mark Briggs, Principal Engineer, Elliott Laboratories- An NTS Company

Note: This information was last updated October 25, 2010 to include the FCC's latest release regarding the 5470-5725MHz band for outdoor systems and confirm the EU's intent to adopt 0.5µs pulse widths by 2012..

The advent of the 802.11a wireless market and the constant push to open up spectrum for unlicensed use created a requirement for Dynamic Frequency Selection (DFS), a mechanism to allow unlicensed devices to use the 5 GHz frequency bands already allocated to radar systems without causing interference to those radars. The concept of DFS is to have the unlicensed device detect the presence of a radar system on the channel they are using and, if the level of the radar is above a certain threshold, vacate that channel and select an alternate channel.

The regulatory requirements for DFS, along with requirements for Transmit Power Control (TPC) and uniform channel loading, have been adopted in Europe, the United States of America, and many other geographical areas. In the next few chapters I hope to provide an overview of the current and proposed DFS requirements for Europe, the current DFS requirements for the USA and how they relate to requirements in Canada, Taiwan, Australia, and Japan.

General Overview of DFS

Standards that incorporate DFS define various requirements for the detection of radars using the following terms.

Channel Availability Check Time: The time a system shall monitor a channel for presence of radar prior to initiating a communications link on that channel. This is also referred to by the acronym CAC.

Interference Detection Threshold: The minimum signal level, assuming a 0dBi antenna, that can be detected by the system to trigger the move to another channel.

Channel Move Time: The time for the system to clear the channel and measured from the end of the radar burst to the end of the final transmission on the channel.

Channel Closing Transmission Time: The total, or aggregate, transmission time from the system during the channel move time.

Non-Occupancy Time: A period of time after radar is detected on a channel that the channel may not be used.

Master Device: Device that has radar detection capabilities and can control other devices in the network (e.g. an Access Point would be considered a master device)

Client Device: Device that does not initiate communications on a channel without authorization from a master device (e.g. a laptop WiFi card – note that a WiFi card that supports ad-hoc mode would be considered a master device)

Radio Local Area Network (RLAN) or *Wireless Local Area Network (WLAN)*: Generic terms for wireless systems such as 802.11a and 802.11n that operate in the 5GHz unlicensed bands.

Uniform Loading or Uniform Spreading: A requirement in many DFS standards to achieve a uniform loading across the available spectrum over a number of devices. It can be achieved by random channel selection in a single device (such as an access point used in a home) or planned selection by a management tool over a large number of devices (such as a coordinated series of networks in a campus).

The operation of a system with DFS capability takes the following sequence (refer also to *Figure 1*):

The master device selects a channel and monitors that channel for potential radar interference for a minimum listening time (channel availability check time). No transmissions can occur during this period. If interference is detected then the system has to go and select another channel and repeat the channel availability check on the new channel (the original channel is added to a list of channels with radar).

Once a channel has been selected and passes the channel availability check interference the network starts to use that channel.

While using the channel the network's master device continuously monitors for potential interference from a radar source (this is referred to as *in-service monitoring*). If interference is detected then the network master device issues commands to all other in-network devices to cease transmissions. The channel is added to the list of channels with radar and the master device then selects a new channel (one that is not on the list). The sequence starts again with a channel availability check.

A channel on the radar list can be purged once the non-occupancy period has elapsed for that channel

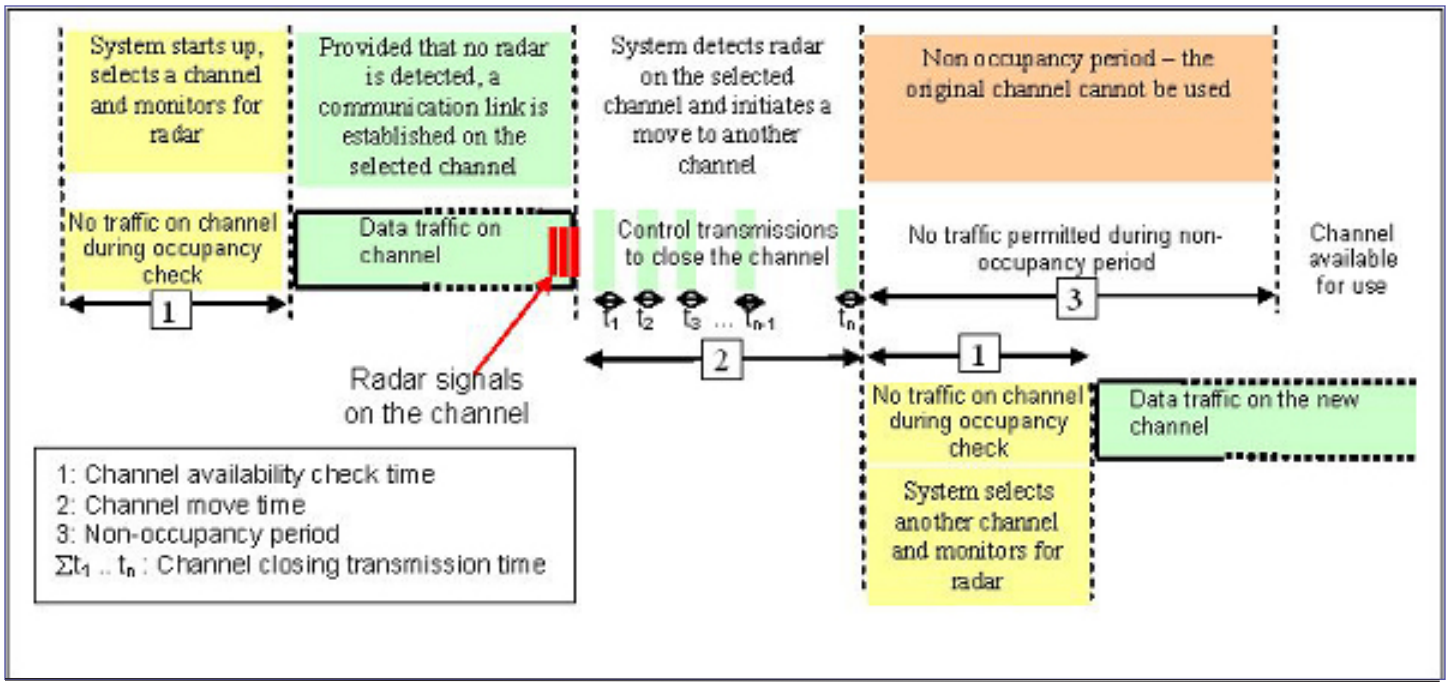

Figure 1 DFS Timing Requirements

While master devices are required to employ interference detection capabilities, client device generally only need to be capable of responding to the master device's instructions to clear the channel. This means that client devices cannot employ active scanning techniques to find a network but must rely on passive scanning (listen-only) to find a network to join.

Point-to-point communication links operating in the DFS bands need to consider the implications of the radar interference potential at one end of the link will be very different from the interference potential at the other end of the link. For this reason it is expected that both ends of the link should be performing radar detection functions. The ETSI technical report TR 102 651 V1.1.1 [*1*] provides additional guidance in implementing a DFS strategy for various wireless network configurations.

To evaluate the DFS functions of a system the regulatory standards describe waveforms to be used when evaluating DFS. These waveforms are defined in terms of the number of pulses, the pulse width and the pulse repetition frequency (or period) for the radar signal. The pulses may be modulated with an FM chirp, and may contain pulses of different widths and different periods. Manufacturers should always bear in mind that their radar detection algorithms should be designed to detect all radar systems.

DFS in the European Union

ETSI standard EN 301 893 V1.5.1[*2*],the European Union's harmonized radio standard for unlicensed devices operating in the 5150 – 5350 MHz and 5470 – 5725 MHz frequency bands, contains DFS requirements. This version of the standard superseded the V1.4.1 version on June 30, 2010. It specifies the types of waveforms that systems operating in the 5250 – 5350 MHz and 5470 – 5725 MHz bands should be able to detect, the maximum allowed values for closing and move times and the minimum channel availability check time. EN 301 893 does not require this feature for client devices provided that they:

• operate below a power level of 200mW;

• are not capable of initiating communication on a channel (in effect, this prohibits them from using active scanning to detect a wireless network);

• only operate on a channel under control of a device with the detection capability (master device);

• respond to the commands to move to another channel from the master device

• meet the channel move time and channel closing transmission time.

To demonstrate the DFS capability a system (master/client pair) is evaluated for its ability to detect different pulse patterns in the presence of data traffic between the two (30% traffic is the requirement of EN 301 893 V1.5.1). There are a total of seven different radar types.

Table 1: EN 301 893 V1.5.1 Radar Parameters

	Pulse Width (µs)	prf (pps)	Pulses per burst[3]	Pulse Modulation	Bursts per waveform	Success Rate
Reference[1]	1	700	18	None	1	N/A
Type 1	0.8 – 5	200 - 1000	10	None	1	> 60%
Type 2	0.8 – 15	200 – 1600	15	None	1	> 60%
Type 3	0.8 – 15	2300 – 4000	25	None	1	> 60%
Type 4	20-30	2000 – 4000	20	± 2 . 5 M H z chirp	1	> 60%
Type 5[2]	0.8 – 2	300 – 400	10	None	2 or 3	> 60%
Type 6[2]	0.8– 2	400 – 1200	15	None	2 or 3	> 60%

[1] The reference waveform is used for validating channel availability check and channel closing times.

[2] For waveforms 5 and 6 the radar bursts shall be interleaved. The difference between the pulse periods shall be 20 - 50 pps for type 5 and 80 - 400 pps for type 6. The pulse width and number of pulses per burst is the same for all bursts within the waveform.

[3] For the CAC and Off-Channel CAC requirements, the minimum number of pulses (for each PRF) for any of the radar test signals to be detected in the band 5600 MHz to 5650 MHz shall be 18.

Additional notes:
Devices capable of operating in the 5600-5650 MHz band can omit channels in that band from the usable channels at start-up.
The minimum percentage of spectrum in any band that the device must be capable of using is 60 %.

The previous version of the standard (V1.4.1) allowed the Channel Availability Check (CAC) to be valid for up to 24 hours after the CAC was performed without requiring continuous monitoring of the channel (something not allowed by the FCC standard). EN 301 893 V1.5.1 removed that capability but introduced the concept of the Off-Channel CAC. The Off Channel CAC allows a device to scan channels for radar on a non-continuous basis while operating on another channel. This allows a system to immediately jump to a new channel, without having to perform the CAC, provided the new channel has been scanned for the Off-Channel CAC period immediately before use.

The system (master/client combination) is considered to have met the DFS requirements if the timing and threshold parameters comply with the values listed in Table 2. The table includes the requirements from the previous V1.4.1 version for reference.

Table 2 EN 301 893 V1.4.1 vs EN 301 893 V1.5.1 DFS Requirements		
Parameter	EN 301 893 V1.4.1 Requirement	EN 301 893 V1.5.1 Requirement
Minimum channel availability check time (CAC time)	60s	60s outside 5600-5650 MHz 10 minutes for 5600-5650MHz sub-band
Off-channel channel availability check time	Off-channel CAC not implemented in this standard.	Up to 4 hours outside 5600-5650 MHz Up to 24 hours for 5600-5650MHz sub-band
Channel Move time	10s (maximum)	10s (maximum)
Channel Closing Time	260ms (maximum)	1s (maximum)
Interference Detection Threshold	-64dBm Transmit power > or = 200mW -62dBm Transmit power < 200mW	DFS Detection Threshold (dBm) = -62 + 10 - EIRP Spectral Density (dBm/MHz) + G (dBi) Shall not be lower than -64 dBm assuming a 0 dBi receive antenna gain.
Non-occupancy period	30 minutes (minimum)	30 minutes (minimum)
Note – Client devices do not need radar detection capabilities unless they have an output power (eirp) that exceeds 200mW. All devices need to demonstrate compliance with the channel move and channel closing times.		

The detection of 0.5µs pulse widths is scheduled to be implemented by April 2012 through EN 301 893 V1.6.1.

DFS in the USA

The FCC opened up the 5150 – 5250 MHz and 5250 - 5350 MHz bands when it originally adopted the UNII rules into Part 15 Subpart E. The FCC added the 5470 – 5725 MHz band to the UNII rules by working with the wireless industry and the Department of Defense through the Department of Commerce, National Telecommunications and Information Administration (NTIA) and in 2003 released its Report and Order FCC 03-287[***3***]. To allow unlicensed use of 5470 – 5725 MHz a requirement for DFS was proposed to cover both this new band and the existing 5250 – 5350 MHz band. The timing and threshold requirements were almost identical to those in EN 301 893 v1.2.3, but the signal parameters were different and included a frequency hopping radar. It took almost three years for the parties involved to settle on an acceptable test procedure and radar parameters and the 5470-5725 MHz DFS procedures did not get released until January 2006. The final list of parameters for the six different radar waveforms are detailed in *Table 3, Table 4 and Table 5*. Where a range of values are listed, each parameter would be selected at random from the range of possible values for each trial.

Table 3 FCC Radar Waveforms 1- 4 – Short Sequence Radar				
Fixed Frequency Radar Type	Pulse Width (µsec)	PRI (µsec)	Pulses per burst	Minimum Detection Probability
1-Fixed	1	1428	18	60%
2- Variable	1-5	150-230	23-29	60%
3- Variable	6-10	200-500	16-18	60%
4- Variable	11-20	200-500	12-16	60%
Average detection probability for types 1 - 4				80%
The minimum number of trials for each waveform is 30.				

Table 4 FCC Radar Waveform 5 – Long Sequence Radar					
Pulse Width (µsec)	PRI (µsec)	Chirp Width	Pulses per burst	Number of Bursts	Minimum Detection Probability
50-100	1000-2000	5 – 20 MHz	1 - 3	8 - 20	80
The 12-second waveform is split into n equal intervals, where n is the number of bursts (e.g. for 10 bursts, the interval is 1.2s) A burst is contained within each interval Within a burst the pulses have the same width and modulation, but not the same repetition interval The first pulse in the burst appears at a random time in the burst's interval The minimum number of trials is 30					

Table 5 FCC Radar Waveform 6 – Simulated Frequency Hopping Radar					
Pulse Width	PRI	#Pulses per Frequency Hop	Hopping Sequence Length	Hopping rate	Minimum Detection Probability
1 µs	333 µs	9	300 ms	333 Hz	70%
Radar hops over the entire frequency range 5250 – 5724 MHz (475 channels) The radar hops across 475 channels in a random manner without using the same channel twice A 100 channel sequence is defined and applied ONLY if the sequence includes one or more frequencies that fall in the detection bandwidth of the device under test The minimum number of trials is 30					

Since release of these requirements interference problems between 5 GHz unlicensed devices and radar systems were reported, leading to a hold on the issue of grants for master devices in mid 2009 while the FCC worked on ways to mitigate this problem. On October 8, 2009, the FCC introduced interim measures (refer to KDB 443999 on the FCC Knowledge Database) that restricted the approval of master devices in the 5470-5725 MHz band to those devices that were limited to operating indoors only.

The FCC has continued to work with industry, the FAA and NTIA to modify the parameters of radar waveform #1 and the test methods to open up the 5470-5725 MHz band for outdoor use. In October 2010 the FCC announced interim procedures [***4***] to allow outdoor systems to be approved for use in the 5470-5725MHz band. Those procedures allow certification of master devices for outdoor or indoor use under the following conditions:

- Devices will not transmit on channels which overlap the 5600 – 5650 MHz band.
- Devices intended for outdoor use will be further restricted, as follows:
  - Devices must be professionally installed when operating in the 5470 – 5725 MHz band
  - Grantees must provide owners, operators and all such installers with specific instructions in their user's manual on requirements to avoid interference to TDWRs and information that meets the following instructions:
    Any installation of either a master or a client device within 35 km of a TDWR location shall be separated by at least 30 MHz (center-to-center) from the TDWR operating frequency (there is a table of locations provided in the FCC's document)
  - The grantee must identify the specific expertise and the training required by the installers for installing these types of devices.
  - Procedures for the installers and the operators on how to register the devices in the industry-sponsored database with the appropriate information regarding the location and operation of the device and installer information is included.
- Devices must meet all of the other requirements specified in Section 15.407, and it is prohibited to include configuration controls (e.g. country code settings or other options to modify DFS functions) to change the frequency of operations to any frequency other than those specified on the grant of certification for US operation.7
- All applications for equipment authorization must clearly show compliance with all of the technical requirements under worst case parameters, under user or operator control, based on frame rates, listen/talk ratios and user data transfer conditions.

Applications for certification of devices that have radar detection capabilities (master devices) must be filed directly with the FCC. In addition the FCC will perform a pre-grant sample audit test (this means that products will not be certified until the FCC has successfully completed their own audit tests of the device against these DFS requirements). The FCC encourages the applicant to attend these tests to ensure that any special operating software is correctly loaded. Devices being tested by the FCC must contain special test software to facilitate a quick test. Those features are described in the FCC's document, KDB 594340, available through their online knowledge database (https://fjallfoss.fcc.gov/oetcf/kdb/index.cfm).

[1] **The grantee must identify the specific expertise and the training required by the installers for installing these types of devices**

Canada

Canada followed the original FCC requirements with regards to DFS for the 5250 – 5350 MHz and 5470 – 5725 MHz bands with the exception of not allowing any operation in the 5600 – 5650 MHz sub-band. The technical standard RSS 210 has some very generic requirements (similar to the DFS requirements contained in FCC Part 15). Certifications are based on the FCC's test methods for evaluating DFS.

Australia/New Zealand

Australia and New Zealand require DFS capabilities for the 5250 – 5350 MHz and 5470 – 5725 MHz bands. The radio standard AS/NZS 4268 references the use of either EN 301 893 or FCC Part 15 procedures for evaluating DFS capabilities. The AS/NZS 4268 standard and the associated frequency allocation (the LIPD Class Licence and GURL) prohibit the use of the 5600 – 5650 MHz sub-band.

Taiwan

The requirements for 5 GHz Wireless LAN devices are contained in the Low-power Radio-frequency Devices Technical Regulations LP0002. DFS is required for devices operating in the 5470-5725 MHz band. Certification tests use the FCC's technical requirements and methods for evaluating DFS, limited to the 5470 – 5725 MHz band.

Japan

Japan's requirements for low power data communications systems operating in the 5GHz band (5150 – 5250, 5250 – 5350 and 5470 – 5725 MHz) include DFS and carrier sense capabilities. Carrier sense is required for all three bands and refers to the ability of a device to sense a continuous wave signal before transmitting its data – if the signal is there it should wait until the signal has gone before sending its data.

The DFS requirements are similar to those for the FCC in terms of radar parameter and apply to the 5250 – 5350 MHz and 5470 – 5725 MHz bands. If radar-type signals are detected then, as with Europe and North America, the wireless network needs to move to another channel. The radar waveform parameters are different for the 5250-5350 MHz (refer to Table 6) and 5470-5725 MHz bands (refer to Table 7, Table 8 and Table 9).

Table 6 Japan Fixed Radar Parameters – W53 Band (5250-5350 MHz)

Radar test signal	Pulse width W [μs]	Pulse repetition frequency PRF [pps]	Pulses / burst	Detection probability
Fixed Pulse 1	1.0	700	18	See note below
Fixed Pulse 2	2.5	260	18	
Device passes if it detects at least 15 of the first 20 trials or at least 11 times in the first 20 trials and at least 24 times in 40 trials.				

Table 7 Japan Fixed and Variable Radar Parameters – W56 Band (5500-5700 MHz)				
Radar test signal	Pulse width W [µs]	Pulse repetition frequency PRF [pps]	Pulses / burst	Detection probability
Fixed Pulse 1	0.5	720	18	See note below
Fixed Pulse 2	1.0	700	18	
Fixed Pulse 3	2.0	250	18	
Variable Pulse 4	1 - 5	4,347 – 6,667 Hz	23-29	
Variable Pulse 5	6 - 10	2,000 – 5,000 Hz	16-18	
Variable Pulse 6	11 - 20	2,000 – 5,000 Hz	12-16	
For each individual test signal type, the device passes if it detects at least 15 of the first 20 trials or at least 11 times in the first 20 trials and at least 24 times in 40 trials. In addition the mean of the probabilities needs to be at least 80%.				

Table 8 Japan Chirped Radar Parameters – W56 Band (5500-5700 MHz)					
Radar Type	Pulse Width (µsec)	Chirp Width (MHz)	PRI (µsec)	Pulses / burst	Number of Bursts
Chirp	50-100	5-20	1000-2000	1-3	8-20
Device passes if it detects at least 18 of the first 20 trials or at least 15 times in the first 20 trials and at least 32 times in 40 trials.					

Table 9 Japan Frequency Hopping Radar Parameters – W56 Band (5500-5700 MHz)					
Radar Type	Pulse Width (µsec)	PRI (µsec)	Pulses / hop	Hopping Rate (kHz)	Hopping Sequence Length (msec)
Hopping	1	333	9	0.333	300
Device passes if it detects at least 16 of the first 20 trials or at least 11 times in the first 20 trials and at least 28 times in 40 trials.					

Conclusions

As the 5GHz bands are opened up in other geographic areas it can be expected that DFS requirements will be included in each country's spectrum allocation. Similar types of channel access provisions, such as Listen before Talk, will be a key regulatory tool to allow spectrum allocations to be shared by different wireless systems as our use of wireless technologies continues to expand.

For more information about how this change affects your products or for a price quote to test your product for DFS, please contact us at svinfo@ntscorp.com or call at 408-245-7800.

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1 ETSI TR 102 651 V1.1.1 (2009-06) Technical Report, Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Guide to the implementation of Dynamic Frequency Selection (DFS), published by ETSI and available at www.etsi.org

2 EN 301 893 V1.5.1, "Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering essential requirements of article 3.2 of the R&TTE Directive" , published by ETSI and available at www.etsi.org

3 Federal Communications Commission Report and Order FCC 03 287 released November 18, 2003

4 Federal Communications Commission KDB 443999 D01 Approval of DFS UNII Devices v01 October 14, 2010 available at https://fjallfoss.fcc.gov/oetcf/kdb/index.cfm - enter 443999 in the Run Publication # Search field.

Revision Index

This article was last revised on June 2010. Following are the links to our previous articles:
http://www.elliottlabs.com/documents/eu_dynamic_frequency_selection.pdf
http://www.elliottlabs.com/documents/dynamic_frequency_selection_and_5ghz_band.pdf

Mark Briggs is a Principal Engineer with Elliott Labs (www.elliottlabs.com, info@elliottlabs.com), a test lab, TCB and Conformity Assessment Body (CAB) in the San Francisco Bay Area. Mark has been involved in EMC and Radio testing for the last 15+ years.

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