IEEE P802.11
Wireless LANs

IEEE802.11h
Dynamic Frequency Selection (DFS) in an Independent BSS (IBSS)

Date: September 21, 2001

Author: S. Black[1], S. Choi[2], S. Gray[1], A. Soomro[2]
Nokia Research Center[1] and Philips Research[2]

e-Mails: [simon.a.black, steven.gray]@nokia.com, [amjad.soomro, sunghyun.choi]@philips.com

Abstract

This paper outlines a method of providing dynamic frequency selection (DFS) within an IEEE802.11 independent BSS (an IBSS). The method takes into account the imperfect nature of IBSS communication. The scheme is based on a central co-ordination principle (the DFS Owner), though a distributed timing scheme and channel map concept ensure that (a) any STA is able to fulfil the DFS owner role at any time and (b) channel information as seen by each STA is shared.

1. FRAME DEFINITIONS

1.1 Measurement Interval Frame

The Measurement Interval frame is a Control type frame that allows a STA to quieten the medium for a period to improve the accuracy of on-channel measurements. The Measurement Interval frame is a Class 1 frame.

The format of the Measurement Interval control frame is as defined in Figure 1. The subfields of the Frame Control field shall be set as defined in [1] §7.2.1. The frame type and Subtype shall be as defined in Figure 1. The Duration value shall be set to 0. The RA shall be the broadcast address. The BSSID shall be the BSSID of the current BSS. Quiet Period shall specify the desired channel quiet period as an integral number of Slot Times.

Standard medium access rules shall be used for Measurement Interval frames. An STA that transmits a Measurement Interval frame shall not transmit any frames other than additional Measurement Interval frames in the requested channel quiet period. STAs receiving the Measurement Interval frame that are members of the BSS indicated by the BSSID field shall not transmit any frames in the requested channel quiet period. The channel quiet period shall commence at the slot boundary one SIFS time after the end of the Measurement Interval Control frame.

	Frame Control	Duration	RA	BSSID	Quiet Period	FCS
	Type = Control (1) SubType = Measurement Interval (3)	0	Broadcast Address		Slot Times	
Length (octets):	2	2	6	6	2	4

Figure 1: Measurement Interval Control Frame

1.2 IBSS Channel Switch Announcement Frame

As the distributed Beacon transmission protocol does not provide deterministic transmission opportunities, a new management frame is required for channel switch announcements in an IBSS. The channel switch announcement shall use the {generic} Action frame format defined in [3] §7.2.3.12. The Category code shall be set to a value of 4 (Spectrum Management) and the Action code shall be set to 2 (IBSS Channel Switch Announcement). The Activation Delay shall be set to the number of TBTTs until the intended channel switch event. The Dialog Token field is unused. There shall be a single Action-specific fixed field indicating the intended channel and no Action-specific elements. See Figure 2.

	Category Code	**Action Code**	**Activation Delay**	**Dialog Token**	**Channel Number**
	Category 4 Spectrum Management	Action 2 IBSS Channel Switch Announcement		0 Unused	
Length (octets):	1	1	1	1	1

Figure 2: IBSS Channel Switch Announcement Frame Body

1.3 IBSS DFS Element within Beacon and Probe Response Management Frames

An IBSS DFS element shall be defined. This element shall be included in Beacon and Probe Response management frames from STAs in a spectrum managed IBSS.

Table 1 – Beacon frame body

Order	Information	Notes
11	Country	The Country Information element shall be present when dot11MultiDomainCapabilityEnabled or dot11SpectrumManagementCapabilityEnabled is true
20	Power Constraint	Power Constraint as specified in clause shall be included if dot11SpectrumManagementCapabilityEnabled is true
21	Channel Switch Announcement	Channel Switch Announcement as specified in clause *may* be included if dot11SpectrumManagementCapabilityEnabled is true
tbd	**IBSS DFS Element**	**The IBSS DFS Element shall only be present in beacon frames from STAs in a spectrum managed IBSS (dot11SpectrumManagementCapabilityEnabled = True)**

Table 2 Probe Response frame body

Order	Information	Notes
10	Country	The Country Information element shall be present when dot11MultiDomainCapabilityEnabled or dot11SpectrumManagementCapabilityEnabled is true
14	Power Constraint	Power Level Adjustment as specified in clause shall be included if dot11SpectrumManagementCapabilityEnabled is true
15	Channel Switch Announcement	Channel Switch Announcement as specified in clause *may* be included if dot11SpectrumManagementCapabilityEnabled is true
tbd	**IBSS DFS Element**	**The IBSS DFS Element shall only be present in probe response frames from STAs in a spectrum managed IBSS (dot11SpectrumManagementCapabilityEnabled = True)**

1.3.1 IBSS DFS Element Definition

The IBSS DFS Element contains the parameters necessary to support the IBSS DFS protocol. The element contains five fields: DFS Owner, DFS Interval, DFS Recovery Interval, DFS Count, and Channel Map. See Figure 3.

	Element ID	Length	DFS Owner	DFS Interval	DFS Recovery Interval	DFS Count	Channel Map
Length (octets):	1	1	6	2	1	2	2 * n

Figure 3: IBSS DFS Element Format

The DFS Owner field shall be set equal to the IEEE individual MAC address of the STA that is the current DFS Owner in the IBSS.

The DFS Interval field indicates the maximum time in normal operation that the IBSS will remain on a channel without re-evaluating the interference characteristics of that channel. DFS Interval is expressed as an integral number of beacon intervals. DFS Interval shall be chosen to meet any regulatory constraints. DFS Interval is static throughout the lifetime of the IBSS and is determined by a parameter to MLME-START at the STA that initiates the IBSS.

The DFS Recovery Interval field indicates the time interval that shall be used between a DFS Interval expiry and the switch to a new channel during the DFS Recovery procedure. DFS Recovery Interval is expressed as an integral number of beacon intervals and shall be sufficiently long to allow for multiple DFS Owner resolution. The DFS Owner recovery procedure shall be used to maintain DFS operation when a DFS Owner fails to announce a channel switch before the DFS interval expires (see §2.4). DFS Recovery Interval is static throughout the lifetime of the IBSS and is determined by a parameter to MLME-START at the STA that initiates the IBSS.

The DFS Count field indicates the integral number of beacon intervals remaining until the start of the channel decision process. The DFS Owner shall determine the initial value of DFS Count in each DFS interval. DFS Count shall be sufficiently smaller than DFS Interval to allow for DFS Owner decision processing and channel switch announcement. DFS Count shall decrement by one each beacon interval until it reaches zero. A value of zero shall be maintained until a new value is determined by the DFS Owner in the next DFS Interval. See Figure 6 in §2.4.

The Channel Map field indicates the current channel characteristics for each channel in the BSS Supported Channel Set. The Channel Map field consists of pairs of channel number and channel characteristics sub-fields – see Figure 4. A channel map shall be a fixed length and shall contain a channel number/channel characteristics pair for each channel in the BSS Supported Channel Set. Channels shall always appear in the map in ascending numerical order. Each channel may be as characterised by collective agreement between the members of the IBSS – termed a global channel characteristic, or as seen at a local STA – termed a local channel characteristic. The channel map generated by the DFS Owner is termed the *global* channel map. Channel maps transmitted by individual STAs that include local characteristics are known as *local* channel maps.

	Channel Number a	Channel Characteristics a
	Channel Number b	Channel Characteristics b
	Channel Number c	Channel Characteristics c
	…	…
Length (octets):	1	1

Figure 4 – Channel Map Field in IBSS DFS Element

The channel characteristics sub-field contains the parameters necessary to support the IBSS DFS protocol. The sub-field contains five one-bit flags: Local, Unmeasured, Periodic, Foreign PLCP, BSS and a three-bit RSSI field. See Figure 5.

Bit	0	1	2	3	4	5	6	7
Sub-field	RSSI0 (lsb)	RSSI1	RSSI2 (msb)	BSS	Foreign PLCP	Periodic	Un-measured	Local

Figure 5 – Channel Characteristics Sub-Field in Channel Map Field

Each bit in the Channel Characteristics field is defined as follows:

Local:
The Local flag shall be set to '1' if the channel characteristics for this channel in the global channel map have been overridden by the local STA. Otherwise it shall be set to '0'.

Unmeasured:
The Unmeasured flag shall be set to '1' to indicate an unmeasured channel. Otherwise it shall be set to '0'.

Periodicity:
The Periodicity flag shall be set to '1' if at least two consecutive CCA busy on/off patterns were periodic. A signal shall be classified as periodic if at least two consecutive CCA Busy Duration and CCA Busy Intervals are identical. The margin of error for these measurements shall be no more than ±1 time slot. Otherwise it shall be set to '0'.

ForeignPLCPHeader:
The ForeignPLCPHeader flag shall be set to '1' if at least one PLCP Preamble was detected, but no valid SIGNAL field was subsequently detected. Otherwise it shall be set to '0'.

BSS:
The BSS flag shall be set to '1' if an IEEE802.11 BSS was detected on the channel by; (1) reception of an IEEE802.11 Beacon, or Probe Response management frame, or (2) reception of a valid IEEE802.11 data frame. Otherwise it shall be set to '0'.

RSSI[2-0]:
The RSSI value shall be used to report the received signal power level in the channel during the measurement interval. Reporting is based on the Received Signal Strength Range Index statistics defined in [2] §7.3.2.28). The RSSI value shall be the mean RSSRI during the measurement interval rounded up to an integer value. RSSI shall be calculated as follows:

$$RSSI = ROUND\left\{\frac{\sum_{RSSRI=0}^{7}\left[RSSRI \times Density\left(RSSRI\right)\right]}{256}\right\}$$

2. PROTOCOL DEFINITION

2.1 Activation of Spectrum Management in an IBSS

The use of spectrum management in an IBSS shall be determined by the STA that starts the IBSS. If the MIB attribute dot11SpectrumManagementEnabled (TruthValue, default = *true*) is set equal to *true* when the MLME-START primitive is issued, then the IBSS will be spectrum managed and shall follow the protocol procedures defined here.

2.2 Starting an IBSS

A STA starting an IBSS shall first measure sufficient channels within the intended BSS Supported Channel Set to find a channel with Periodicity, Foreign PLCP and BSS flags clear and an RSSI value less than, or equal to '1'. This channel shall be the initial operating channel of the IBSS. The measurement data collected shall be formatted into a channel map as defined above.

In the event that a suitable channel cannot be found, the least significant six bits of each of the channel characteristics octets in the map shall be considered as integer values (0…63). The initial operating channel shall be that with the minimum value. In the event that more than one channel has this value, a random slection shall be made from the set of minimum value channels. Channels that have not been measured – indicated by the Unmeasured flag set to '1', shall not be included in the selection

The BSS Supported Channel Set, DFS Interval and DFS Recovery Interval shall be specified in the appropriate parameters in the MLME-START primitive. These operating parameters shall be static for the life of the IBSS. The STA shall then commence the IBSS Beacon generation procedure as specified in §11.1.2.2 of [1]. The DFS Owner shall determine the initial value of DFS Count and this shall be included in the first beacon sent. DFS Count will then begin to decrement as described above. The DFS Owner address shall be set to the individual IEEE MAC address of the initiating STA. The Channel Map field shall contain a global channel map containing the results of the initial scan. This STA shall be the initial *DFS Owner* in the IBSS (see §2.4).

2.3 Joining an IBSS

A STA joining an IBSS shall adopt the BSS Supported Channel Set, DFS Interval, DFS Recovery Interval and DFS Count from the same Beacon, or Probe Response management frame that is used for synchronisation to the IBSS (see [1] §11.1.3.4). The STA shall also record the received channel map from this frame as a global channel map for the IBSS, noting if there are local variations by examining the local flags in each Channel Characteristics sub-field. If a local bit for a given channel is set, the STA shall record the channel characteristics for that channel as local characteristics for the STA given by the Address 2 field of the frame (the Transmitter Address). By this mechanism, the STA has access to all required DFS data from the moment that it joins the IBSS and is able to generate the required IBSS DFS element within Beacon and Probe Response management frames that it transmits. The STA shall classify channels for which only local channel characteristics have been received as unmeasured in Channel Map fields that it transmits.

If the STA does not support the Spectrum Management Capability, or all of the channels in the BSS Supported Channel Set, the MLME join procedure shall fail with the MLME-JOIN.confirm result code INVALID_PARAMETERS.

2.4 The DFS Owner

The STA that is *DFS Owner* is responsible for creating a revised global channel map and making the decision on next operating channel before the DFS interval expires. The DFS Owner role circulates among the STAs within the IBSS. The initial DFS Owner shall be the STA that started the IBSS (the STA at which the MLME-START primitive was issued). Thereafter, the STA that transmits the Beacon for the first TBTT in the new operational channel shall become the DFS Owner.

The DFS Owner shall commence the process to select a new operating channel at the TBTT when the DFS Count reaches 0. The process of selecting a new channel is detailed in §2.6 below. The process may include additional

channel measurements by the DFS Owner. The DFS Owner shall then announce a channel switch by sending an IBSS Channel Switch Announcement frame. The Address 1 field of this frame shall be set to the broadcast address. The Activation Delay field shall indicate the number of TBTTs until the intended channel switch. The channel switch shall be scheduled to occur at, or before the end of the current DFS Interval. The DFS Owner may send the Channel Switch Announcement frame more than once before the intended channel switch time. The DFS Owner shall also include the Channel Switch Announcement element defined in [2] §7.3.2.25 in each Beacon, or Probe Response frame transmitted until the intended channel switch time. The Channel Switch Count field shall be set to indicate the appropriate switch time and shall decrement at each TBTT. Channel switching shall be as defined in [2] §7.3.2.25 & §9.13.4. Figure 6 illustrates the DFS related timing.

The DFS Owner recovery procedure shall be used to maintain DFS operation when a DFS Owner fails to provide the required functions, e.g. if the STA leaves the IBSS during the DFS Interval in which it is DFS Owner. A STA shall perform DFS Owner recovery if it has not received a Channel Switch Announcement frame, or a Beacon or Probe Response frame containing a Channel Switch Announcement element by the end of a DFS Interval. During DFS recovery the STA that transmits the Beacon for the first TBTT after the DFS Interval expires shall become the DFS Owner. This may result in more than one DFS Owner, though this is rapidly resolved by the procedure defined below.

In order to expedite a channel switch, the Beacon frame scheduled by each STA for DFS recovery shall contain an IBSS DFS element with the DFS Count value set to DFS Recovery Interval. This Beacon frame shall also contain a Channel Switch Announcement element with the channel selected from the revised global channel map according to the algorithm in §2.6, and the Channel Switch Count set equal to the DFS Recovery Interval.

During DFS Owner recovery, STAs shall include both IBSS DFS and Channel Switch Announcement elements in Beacon and Probe Response frames that they transmit. The value of the fields in the IBSS DFS element shall be as defined for normal Beacon transmission in §2.5. The Channel to Switch field in the Channel Switch Announcement element shall be set to the Channel to Switch value determined by the DFS Owner. The Channel Switch Count field shall be set equal to the DFS Count value.

A DFS Owner STA that receives a valid DFS element from a STA in the same IBSS containing a DFS Owner address that differs from its own individual MAC address shall immediately cease to be DFS Owner. The STA shall adopt the DFS Owner address, DFS Interval, DFS Recovery Interval, DFS Count and global Channel Map from the received DFS element. If a Channel Switch Announcement element was received within the same frame, any pending channel switch shall be cancelled and a new channel switch scheduled based on the received information. This is necessary to provide resolution between multiple STAs that have DFS ownership in the same DFS interval through beacon transmissions that have not been received correctly, collisions, or coalescing.

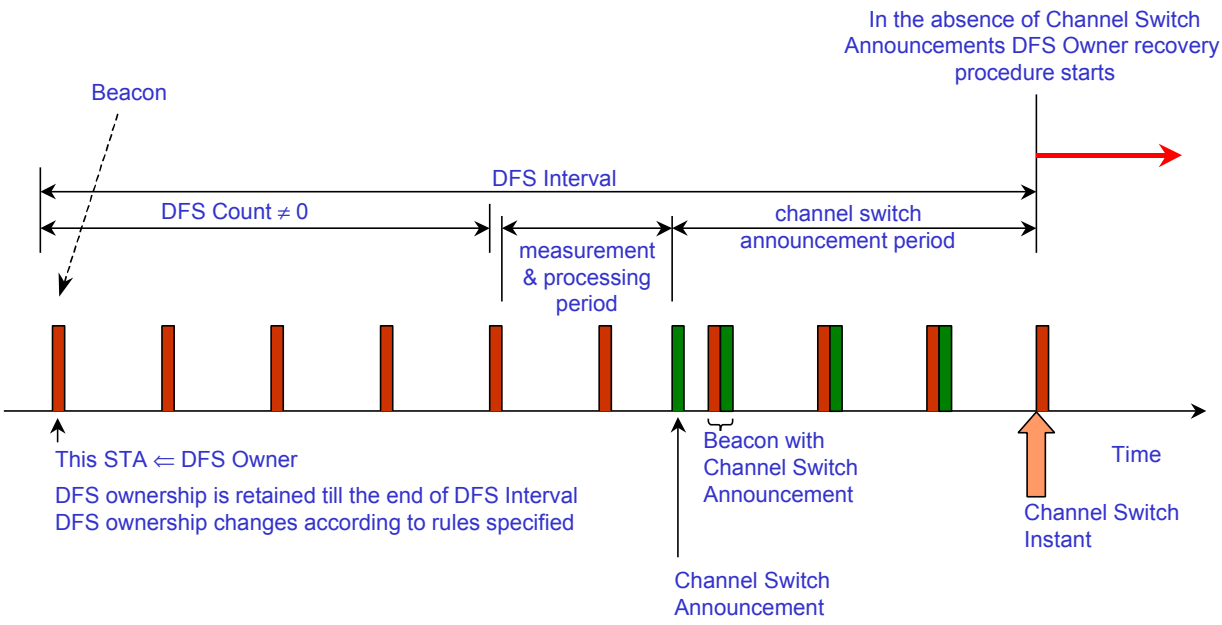

Figure 6 – IBSS DFS Related Timing

2.5 IBSS Station Protocol

STAs that are not the DFS Owner participate in the IBSS management protocols as described in [1] §11.

STAs shall maintain local DFS Owner, DFS Interval, DFS Recovery Interval, DFS Count and global Channel Map information. STAs shall interpret the IBSS DFS element in Beacon and Probe Response frames received from STAs within the same IBSS and shall update the local DFS Count from the value received. If the DFS Owner address in a received Beacon, or Probe Response differs from the locally stored DFS Owner address, the DFS Owner, DFS Interval, DFS Recovery Interval, DFS Count and global Channel Map data shall also be updated. This is necessary to provide resolution between multiple STAs that have DFS ownership in the same DFS interval through beacon transmissions that have not been received correctly, collisions, or coalescing.

STAs shall include the IBSS DFS element in Beacon and Probe Response frames that they transmit. The value of DFS Owner address, DFS Interval, DFS Recovery Interval and global Channel Map in transmitted frames shall be set from the locally stored values. The DFS Count shall be set to the last received value decremented by the number of TBTTs that have expired since that reception.

STAs shall perform measurements on channels in the BSS Supported Channel Set and shall have the capability to report periodicity, foreign PLCP, BSS and RSSI as defined above and in [2]. The timing and exact implementation of the channel measurement process is outside the scope of this standard. STAs should perform channel measurement without serious degradation of data throughput.

The Measurement Interval frame shall be used to quieten the BSS before measurements on the current operating channel. The Measurement Interval frame shall only be sent by the STA that is the current DFS Owner. The Measurement Interval frame may be transmitted more than once to increase the probability that all STAs in the BSS have received it correctly. The Quiet Period requested in an initial Measurement Interval Contol frame shall not be extended. The Quiet Period value in a retransmitted Measurement Interval frame shall be reduced by the number of Slot Times between the start of the Quiet Period and the end of the retransmitted frame plus one SIFS. Any STA that receives a Measurement Interval frame may elect to carry out channel measurements during the Quiet Period. The BSS condition shall only be reported for the current operating channel if frames from a foreign BSS are detected.

STAs shall assume that the DFS owner is not able to receive frames between the TBTT at which DFS Count reached 0 and receiving a channel switch announcement. The DFS Owner may use this period to perform channel measurements. Provided that the IBSS has been initialised with a non-zero ATIM window, a STA that supports IBSS power management may perform channel measurements during periods that it would be permitted to be within a Doze state.

Local channel measurements shall be compared to those received in the global channel map field of IBSS DFS elements. If the periodicity, foreign PLCP, BSS flag, or most significant bit of the RSSI value differs from the received map, the STA shall replace the global channel characteristics sub-field for that channel with its own local channel characteristics sub-field. The local flag in the channel characteristics subfield for that channel shall be set to indicate that this is a local measurement. An STA shall include no more than three local channel characteristics in each channel map that it transmits. The channels that deviate furthest from the global channel characteristics shall be sent at the earliest opportunity. This limitation ensures that STAs that have just joined the IBSS receive mostly global channel characteristics.

When a STA receives a beacon, or probe response it stores any local channel characteristics against the MAC address for that STA in a STA channel map. STAs shall be capable of storing at least five complete STA channel maps, i.e. channel characteristics for all channels within the BSS Supported Channel Set for a minimum of five individual STAs (five MAC addresses). If the STA map storage limit is reached then the STA channel map containing the oldest channel characteristics shall be discarded.

A STA that receives a channel switch announcement will update the Channel Switch Count field and relay that announcement in Beacon and Probe Response management frames that it transmits. The STA shall switch to the specified channel immediately before the announced TBTT as defined in [2] §7.3.2.25.

A STA shall perform DFS Owner recovery if it has not received a Channel Switch Announcement frame, or a Beacon or Probe Response frame containing a Channel Switch Announcement element by the end of a DFS interval. DFS Owner recovery is specified in §2.4.

In the event that a STA has become detached from the IBSS, that STA shall scan for the IBSS and rejoin.

2.6 Global Channel Map Creation and Channel Selection

All STAs that belong to a spectrum managed IBSS shall create revised global channel maps and select preferred operating channels for the IBSS. The initial global channel map shall contain the results of the measurements performed prior to the MLME-START primitive being issued. The initial channel selection shall be derived from the same measurements and specified in the MLME-START primitive. Thereafter, each STA shall create a revised global channel map from the previous global channel map, its own measurements and local channel map information received from other STAs. STAs shall perform this process in each DFS Interval after DFS Count reaches zero.

For each channel, if any of the three conditions listed below is true, the previous global channel characteristic shall be discarded and a new global channel characteristic computed. All local measurements for that channel made during the last DFS Interval shall be used in the computation.

1. If a channel was indicated as unmeasured in the previous global channel map and there exists at least one local measurement.
2. If in any local channel characteristic the Periodicity, Foreign PLCP, or BSS flag is set to ‘1’ where the same flag was set to ‘0’ in the previous global map, or the RSSI value is greater than the previous global RSSI value.
3. If (a) at least two local channel characteristics exist, and (b) in all local channel characteristics, either the Periodicity, ForeignPLCPHeader, or BSS flag is set to ‘0’ where the same flag was set to ‘1’ in the previous global map, or the RSSI value is less than the previous global RSSI value.

To form each revised global channel characteristic all of the local characteristics for that channel shall be used. Each of the Periodicity, ForeignPLCPHeader and BSS flags of the new channel characteristic shall be the logical OR combination of the same flags in each local measurement. The new global RSSI value shall be the maximum RSSI value present in the local measurements.

If a channel was indicated as unmeasured in the previous global map and is indicated as unmeasured in all local channel characteristics, that channel shall be classified as unmeasured in the revised global channel map.

If none of the above conditions applies, then the previous global channel characteristic shall be retained unchanged in the revised global channel map.

The DFS owner shall choose the next operating channel by considering the least-significant six bits of each of the revised global channel characteristics octets in the map as integer values (0…63) and selecting the channel with the minimum value. In the event that more that one channel has this value, the current operating channel shall continue to be used if the set of minimum value channels includes this channel. Otherwise, a random slection shall be made from the set of minimum value channels. Channels that have not been measured – indicated by the Unmeasured flag being set to '1', shall not be included in the selection.

It should be noted that it is permissible for a spectrum managed IBSS to remain on the same channel for more than one DFS Interval if and only if that channel is the optimum operating channel by the rules specified herein. In this case the channel switch announcement protocol shall still apply and the channel announced will be equal to the current operating channel.

3. REFERENCES

[1] ISO/IEC 8802-11-1999
[2] P802.11h/D1.0, July 2001
[3] P802.11e/D1.0, March 2001