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Transmitter Power Control (TPC) and Dynamic Frequency Selection (DFS) Joint Proposal for 802.11h WLAN

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Abstract

This paper contains a revision for the transmit power control (TPC) and dynamic frequency selection (DFS) proposal presented by Philips and Nokia in the March 2001 meeting [1], with some additional features from Cisco proposal [11] in 2.1.1. The methods described within are tailored to the existing 802.11 MAC and 802.11a PHY to allow vendors producing equipment to meet European Radiocommunications Committee (ERC) regulatory requirements in the 5 GHz band. The proposal introduces changes to the 802.11 MAC and 802.11a PHY specifications that will allow transmit power control and dynamic selection of a frequency channel to not only meet the requirements imposed by the ERC, but also to enhance the performance of 802.11 WLAN operation in the 5 GHz band. While some relevant algorithms, such as when to change the transmit power setting and when to initiate the frequency selection, are implementation-dependent, the standard specification should define the mechanisms for TPC and DFS, such as how to communicate between the AP and STAs and what are the allowable power settings. The proposed mechanism requires some modifications in 802.11 MAC as well as 802.11a OFDM PHY specifications.

1 Introduction

The ERC has imposed conditions for the deployment of Radio LANs (RLANs) in 5 GHz band primarily to support coexistence between RLANs and existing satellite and terrestrial based radar systems [3][4][5]. To support coexistence, RLANs must meet the following conditions when operating in domains covered by the ERC:

- 5150-5350 MHz: indoor use, mean EIRP limited to 200 mW, use of Dynamic Frequency Selection and of Transmitter Power Control
- 5470-5725 MHz: mean EIRP limited to 1 W, outdoor and indoor use allowed, use of Dynamic Frequency Selection and of Transmitter Power Control

The ERC decision requires that the 5 GHz RLANs in Europe (which are HIPERLANs currently) must be capable of avoiding occupied channels by employing a Dynamic Frequency Selection (DFS) mechanism and ensuring a uniform spreading of the devices over all the available channels for RLANs [5]. In addition, the ERC decision requires a transmitter power control (TPC) process to ensure a mitigation factor of at least 3 dB on the average output power of RLAN devices. TPC requirement both in up- and downlink are required to reduce the interference effect caused by RLANs under the coverage area of a satellite. The existing IEEE 802.11 WLAN standard does not define necessary TPC and DFS mechanisms to allow manufactures to produce equipment meeting ERC requirements. This paper describes TPC and DFS mechanisms that allow manufactures to produce equipment meeting the requirements of the ERC decision. Furthermore, the scheme as proposed provides a means to improve the radio link conditions of the 802.11 WLAN by adjusting the transmit power setting and dynamically selecting the best operating channel.

For the infrastructure-based 802.11, WLANs with an AP as a centralized decision maker, implementing TPC and DFS within a BSS is aided by defining new information elements for Beacon and other management frames, new management frames and MIB variables that allow the power level to be adjusted and frequency channel changed by the AP. Details description of AP algorithms used to determine when a BSS must change power or frequency channel are not defined, but left to each vendor as part of the overall design. All necessary mechanisms for TPC and DFS are included in this proposal to allow vendors to produce equipment that is compliant with ERC mandates.

TPC requirements for the Ad Hoc mode (i.e., IBSS) are satisfied by reducing the power used all STAs as suggested in [6] by 3 dB from the maximum allowed in the band. For IBSS mode, this method precludes the necessity of standardizing the decision algorithms for determining when to reduce power. Because the Ad Hoc mode is designed as means for few STAs to communication on a temporary basis, the range reduction caused by permanently backing the power off by 3 dB from the peak (EIRP)[1] is minor and should be acceptable.

Our belief is that such relevant algorithms as when or how to change the power or initiate a channel switch should remain implementation-dependent, the standard specification should define the mechanism for TPC and DFS. In this paper, we propose TPC and DFS mechanisms for 802.11 with some minor modification in the current 802.11 specifications. The implementation-dependent algorithms for TPC and DFS would be implemented in the Station Management Entity (SME) of a STA.

2 TPC method

This proposal contains a transmit power control scheme for the (Enhanced) Distributed Coordination Function ((E)DCF), Point Coordination Function (PCF) and Hybrid Coordination Function (HCF). Note that EDCF and HCF are part of IEEE 802.11 TGe QoS draft [8], and hence the details can change. In (E)DCF, all the STAs contend for the channel; thus the proposal contains a suggested common power (in EIRP) that applies to all STAs in a BSS. STAs unable to meet the suggested power limit may associate with the AP at a lower power after notifying the AP that it is unable to meet the suggested transmit power level. STAs transmitting at a power level below the suggested level will encounter degraded throughput due to the inability of other STAs in the BSS to show CCA busy when sensing the channel [9]. The situation in PCF and HCF where STAs are allowed to transmit only when polled is quite different. Specifically, for PCF, media control information is distributed within beacon management frames as part of the CF parameter set and there is no need for other STAs to hear the possible upstream transmissions. Thus, one can limit the transmission power of a STA to such a level that ensures reliable transmission. The same goes to HCF since the uplink or direct STA-to-STA transmissions per being polled via HC are protected by the Duration/ID field specified in the QoS (+)CF-poll from the AP. For HCF (PCF) upon receiving a (QoS) (+)CF-poll, the STA will determine the transmit power for its frame transmissions. The transmit power level will be included in all frames and embedded in the Service field in the PLCP header. The scheme will not affect the basic access scheme, but only mitigates overall interference level and can also increase the battery life of portable devices. The common factor with PCF and HCF is that they use polling as a means to control the uplink transmission between STAs and APs, or the STA-to-STA transmission between STAs.

The rules described above for PCF and HCF cover only uplink and STA-to-STA communications while the ERC decision requires TPC both for up- and downlink. In downlink (i.e. from an AP to STA transmission) it is AP's transmission power that matters. For downlink, it is enough to have a possibility to adjust one's transmission power to a desired level. For coverage and network stability, it's better to have slow and relatively small variations in the AP's transmission power. The algorithm itself is beyond the scope of the standard and it is not proposed in this paper. However, the rate at which the AP can change TX power should be standardized to reduce the chance for oscillations in transmit power (sometimes call cell breathing).

2.1 *TPC With DCF*

With DCF, the transmit power, which should be used by all STAs within the BSS, is conveyed in the beacon. One shortcoming of the approach used in HiperLAN/2 for multiple regulatory domains is the difficulty to match the peak power requirements to that specified by the regulatory domain. For example, HiperLAN/2 currently specifies power in 3 dB steps starting with 30 dBm (EIRP). In the US, the maximum power in the 5 GHz band is calibrated relative to 28 dBm. Thus, the approach taken in this proposal is to specify the maximum power in the band and then offer 16 power levels in 3 dB increments relative to the maximum power setting.

To accommodate the fact that 802.11 WLAN devices must operate in different regulatory domains, the approach used for conveying transmit power is similar to the approach currently taken in 802.11d [10]. Namely, dot11MultiDomainCapabilityEnabled or dot11SpectrumManagementCapabilityEnabled attribute will be set true and the beacon will be augmented as shown in Table 1. The approach will make it easier in the future to add new regulatory domain information in the future. The Country Information Element is shown in Figure 2 where channel

[1] EIRP is defined relative to omnidirectional transmission.

numbers are defined based upon a 5 MHz raster. That is, the nominal carrier frequency f_{center} corresponds to its channel number, $N_{channel}$, as follows:

$$N_{channel} = (f_{center} - 5000 \text{ MHz}) / 5 \text{ MHz}$$

A trio of fields, Figure 2, define the operation over a contiguous set of frequencies defined by the First Channel Number and the Number of Channels where the maximum transmit power is defined by the Maximum Transmit Power Level field. The Maximum Transmit Power Level field is a signed number and shall be one octet in length. It shall indicate the maximum power, in dBm, allowed to be transmitted. This is, this field can indicate the power level from –127 to 128 dBm. The Power Level Adjustment Element in the Beacon, will convey one of 16 possible transmit power settings (in EIRP) relative to the maximum power setting conveyed in the Country Information Element in the Beacon. Note that it is up to the discretion of the implementer concerning the amount of information in the Country Information Element. As a minimum, the AP must transmit one set of First Channel Number, Number of Channels and Maximum Transmit Power as part of the Country Information Element, which includes the current BSS frequency channel number. If the STA is unable to meet the suggested transmit power level conveyed in the Power Level Adjustment Element, then the STA may attempt to associate at a lower power level by informing the AP of its transmit power capability.[2]

For TPC-enabled APs, a STA will include a Maximum Transmit Power Capability information element in the Association Request and Reassociation Request frames, which will allow the AP to know if a STA is unable to meet the Power Setting Relative to Maximum in the Power Level Adjustment Element. These three frames will be augmented as shown in Table 3 and Table 4. The format of the Maximum Transmit Power Capability Information Element is specified in Table 7. Encoding is similar to the Maximum Transmit Power Level: the Maximum Transmit Power Capability field is a signed number and shall indicate the maximum power, in dBm, the STA is capable to transmit at. This is, this field can indicate the power level from –127 to 128 dBm.

In response to the Probe Request, a Probe Response is defined to convey relevant information for the domain of operation. The Probe Response frame is augmented as shown in Table 2.

2.1.1 *Hidden terminal detection*

TPC may be enhanced with method to detect and report a potential hidden terminal. A more thorough description on this issue is given in [11]. More studies are, however, needed in order to define both the detection and reporting mechanisms.

2.2 *TPC for PCF and HCF*

For PCF and HCF, power adjustments are allowed on a per station basis as long as the transmit power is less than or equal to the Power Setting Relative to Maximum field in the Power Level Adjustment Element. The control for transmit power determination lies with the transmitting device. Thus, STAs seeking to minimize transmit power can estimate the path loss between the source and destination to determine the required power to meet each individual STA's operational requirements. To enable STAs to estimate the path loss, the Service field in the PLCP header will be augmented as shown in Figure 1 to include the transmit power levels defined in Power Setting Relative to Maximum field in the Power Level Adjustment Element, Table 10.

B1 B7	B8 B11	B12 B16
Scrambler Initialization	Power Setting Relative to Maximum	Reserved

Figure 1 Augmented Service Field to Include Transmit Power Information

Operationally, after receiving a (QoS) (+)CF-poll from the AP, the polled STA will set its transmit power, write the value in the Service Field as shown above and send a frame. For direct STA-to-STA communications devices may calculate the path loss for the channel between the two devices to determine a good power setting.

[2] Note that STAs associating with a transmit power lower than the suggested level may encounter degraded performance due to increased collisions with STAs unable to detect a busy channel.

2.3 *Proposed Frames and Information Elements*

The proposal builds upon modifications in the Beacon frame and Service field. Order 11 in the Beacon aides both TPC and DFS functionality as it informs a STA as to the available frequency channels and the maximum transmit power allowed in those channels.

2.3.1 *Beacon and Probe Response*

The beacon frame and probe response frames are augmented by a new information element, which is Power Level Adjustment Information element defined in the following section. Use of the Country Information element is redefined for use in regulatory domains supporting 5 GHz spectrum. Beacon Order 11 indicates information about channel number and maximum transmit power. Beacon Order 20 indicates the suggested transmit power setting for its BSS. The information elements contained in the Beacon can also be obtained in the Probe Response as shown in Table 2.

Order	Information	Notes
11(per [8])	Country Information	The Country Information element shall be present when TPC bit is set in Capabilities information and dot11MultiDomainCapabilityEnabled or dot11SpectrumManagementCapabilityEnabled is true
20 (per [8])	Power Level Adjustment	The Power Level Adjustment shall be present when TPC bit is set in Capabilities information; This is transmit power setting relative to Maximum Transmit Power Level defined in Country Information

Table 1 Modification to Beacon for Country Information and Power Level Adjustment Information

Octets: 1	Octets: 1
Element ID	Length
Country String (Octets 1,2)	
Country String (Octet 3)	First Channel Number
Number of Channels	Maximum Transmit Power Level
• • •	
First Channel Number	Number of Channels
Maximum Transmit Power Level	Pad (if needed)

Figure 2 Country Informaion Element in the Beacon and Probe Response [10]

Order	Information	Notes
10 (per [8])	Country Information	The Country Information element shall be present when TPC bit is set in Capabilities information and dot11MultiDomainCapabilityEnabled or dot11SpectrumManagementCapabilityEnabled is true
14 (per [8])	Power Level Adjustment	The Power Level Adjustment shall be present when TPC bit is set in Capabilities information; This is transmit power setting relative to Maximum Transmit Power Level defined in Country Information

Table 2 Modifications to the Probe Response Frame for Spectrum Management

2.3.2 *Association Request*

The association request frame is augmented by a new information element, which is Maximum Transmit Power Capability Information element defined in the following section. This new informational element allows STAs to communicate their maximum power capabilities.

Order	Information	Notes
7	Maximum Transmit Power Capability	The Maximum Trasnmit Power Capability shall be present when TPC bit is set in Capabilities information

Table 3 Modification to the Association Request Frame

2.3.3 *Reassociation Request*

The reassociation request frame is augmented by a new information element, which is Maximum Transmit Power Capability Information element defined in the following section. This new informational element allows STAs to communicate their maximum power capabilities.

Order	Information	Notes
8	Maximum Transmit Power Capability	The Maximum Trasnmit Power Capability shall be present when TPC bit is set in Capabilities information

Table 4 Modification to the Reassociation Request Frame

2.3.4 *New Information Elements*

The following new information elements are defined in conjunction with the proposed TPC mechanism.

Information Element	Element ID
Power Level Adjustment	36
Maximum Transmit Power Capability	37

Table 5 New infrormation element IDs for TPC

2.3.4.1 *Power Level Adjustment element*

The Power Level Adjustment element is as shown in Table 6. The Power Setting Relative to Maximum is used by STAs in the BSS during (E)DCF operation as the suggested power setting relative to the maximum allowed in the frequency channel. For PCF and HCF operation, the specified transmit power setting is the upper limit. The Power Setting Relative to Maximum field is encoded according to Table 7.

Octets: 1	Octets: 1	Octets: 1
Element ID (36)	Length (1)	Power Setting Relative to Maximum

Table 6 Power Level Adjustment Element

2.3.4.2 *Maximum Transmit Power Capability element*

The Maximum Transmit Power Capability element is as shown in Table 7. This element specifies the maximum transmit power a STA is capable of transmitting at in EIRP. Encoding is similar to the Maximum Transmit Power Level: the Maximum Transmit Power Capability field is a signed number and shall indicate the maximum power, in dBm, the STA is capable to transmit at. This is, this field can indicate the power level from –127 to 128 dBm.

Octets: 1	Octets: 1	Octets: 1
Element ID	Length	Maximum Transmit Power Capability

(37)	(1)	

Table 7 Maximum Transmit Power Capability Information Element

2.4 *Encoding for new Information Elements*

First Channel Number	Channel Number
XXX11111	Future Use
XXX11110	Future Use
XXX11101	Future Use
XXX11100	Future Use
XXX11011	Future Use
XXX11010	Future Use
XXX11001	Future Use
XXX11000	Future Use
XXX10111	Future Use
XXX10110	Future Use
XXX10101	161
XXX10100	157
XXX10011	153
XXX10010	149
XXX10001	136
XXX10000	132
XXX01111	128
XXX01110	124
XXX01101	120
XXX01100	116
XXX01011	112
XXX01010	108
XXX01001	104
XXX01000	100
XXX00111	64
XXX00110	60
XXX00101	56
XXX00100	52
XXX00011	48
XXX00010	44
XXX00001	40
XXX00000	36

Table 8. First Channel field from the Country Information Element

Number of Channels	
XXXX1111	Future Use
XXXX1110	Future Use
XXXX1101	Future Use
XXXX1100	Future Use
XXXX1011	Future Use
XXXX1010	10
XXXX1001	9
XXXX1000	8
XXXX0111	7
XXXX0110	6
XXXX0101	5
XXXX0100	4
XXXX0011	3

XXXX0010	2
XXXX0001	1
XXXX0000	Not used

Table 9. Number of Channels field from the Country Information Element

Power Setting Relative to Maximum	**Power correction [dBm]**
XXXX1111	0
XXXX1110	-3
XXXX1101	-6
XXXX1100	-9
XXXX1011	-12
XXXX1010	-15
XXXX1001	-18
XXXX1000	-21
XXXX0111	-24
XXXX0110	-27
XXXX0101	-30
XXXX0100	-33
XXXX0011	-36
XXXX0010	-39
XXXX0001	-42
XXXX0000	-45

Table 10. Power Setting Relative to Maximum field from the Power Level Adjustment Information Element

2.5 *Adjusting Tx Power in Downlink*

In an infrastructure network, the AP power variations should be minimized; the primary outcome of a decrease in AP power is a shrinking of the coverage area. The wide power range specified in this document is not to be taken as an endorsement for large power fluctuations, it up to the manufacturer to decide how many power levels to use at the AP. As long as an AP is capable of reducing its transmission power then this should allow the device to pass ERC tests. Downlink TPC can be considered as a tool for range control. The same applies basically also to an ad-hoc network. The power control is one mechanism to reduce the interference to other co-located systems.

To avoid oscillations in system downlink power control should be relatively slow. First, the power should not change more than ca. 3 dB from one Beacon interval to another, and second, there should be an upper limit for the cumulative power changes in the upward direction over several (or TBD) Beacon intervals. To avoid cell breathing, the power should not be changed in an upward direction and downward direction frequently.

3 Proposed DFS Procedure

The proposed DFS mechanism for 802.11 is composed of the following steps:

- Monitoring of Channels
  - Request for channel measurements by AP
  - Channel measurement process
  - Measurement reports from STAs
- Decision making by AP
- Channel switch announcement by AP
- Switching into the new channel

In the following, we discuss each step in detail.

3.1 *Monitoring of Channels*

Before forming a BSS and during its operation, the AP would monitor and measure the channels to select the best channel for peformance reasons and to possibly meet regulatory requirements in the domain of operation. The protocols for measurement and assessment of channels need to be standardized so that the AP has fair amount of information about the state of the channels and presence of other licensed operators, if any. The frequency of these measurements, the interpretation of the returned reports and the decision criteria to choose a channel of operation would remain implementation dependent and need not be standardized.

An AP may intiate process to monitor a channel, or a set of these, due to the following reasons:

1. Before a BSS is formed by an AP (via MLME-START primitive)
2. After the AP runs a BSS without any associated STA for a certain period of time
3. When the AP and/or one or more STAs experience a bad channel condition persistently
4. When overlapping BSSs are detected
5. Detection of other licensed operators
6. Scanning other channels for better operational characteristics

These cases represent the scenarios where an AP would likely inititate to measure channels and it may perform and request channel measurements; however, it is entirely upto the AP to perform the channel measurements whenever it may deem necessary. The second case is an interesting situation, which is an extension to the first case. That is, a STA may not be able to join a BSS due to severe interference from non-802.11 systems and/or a sustained busy medium from another BSS even though it is within the reception coverage of the desired AP to associate with. While it may be difficult to avoid and/or handle this situation in some cases, one possible way to mitigate this situation is that the AP moves its BSS into another channel after it runs a BSS without any associated STA for a certain period of time. The decision can be assisted by the AP's own channel measurement using the methods described in Section 3.1.2.1. The channel measurement of the current channel can be reported by a STA without being requested by the AP. A STA, for example, may report its measurement when it experiences frequent busy periods due to non-decodable signals (e.g., H/2 signals) or when it detects an overlapping BSS. The standard should allow the possibility of an AP receiving unsolicited measurement responses from a STA and it will be at the discretion of a STA when to generate and send these reports.

3.1.1 *Request for Channel Measurements*

In order to select the best channel to run its BSS, the AP needs to know the status of other channels as well as the current channel. While the status of the current channel may be partially available to the AP, in order to initiate a channel selection, the AP needs to collect the information about other channels as well. This will be done via the channel measurements by other STAs as well as the AP itself. Of course, if the channel selection process has been initiated due to the first two cases in the previous subsection, only the AP will measure the channels. The collection of the channel status information can start by requesting the channel measurements to other STAs via the channel measurement request frames defined in Section 3.5.1.

Which STA(s) measure which channels and how long to measure will remain specific to AP's implementation. This request can be either of unicast, multicast, and broadcast type. There are basically two types of measurements as specified by two different types of information elements defined in Sections 3.5.6.2 and 3.5.6.3.
For a STA which is in the polling list as part of PCF and/or HCF, it may not be desirable for it to be absent from the current channel for a long time due to the latency requirement constraints. In that case, the AP can request this STA to measure a channel more than once, periodically, for a relatively short duration at a time. For example, the STA may be asked to measure a channel for 5 msec after each beacon initiating a CFP for 5 times. During a channel measurement by a STA, the AP must not transmit any frame including (QoS) (+)CF-Poll to such a STA and should buffer the data frames directed to the STA. For this reason, the same channel number could be repeated in *Channel Numbers* field in information element shown in Figure 9. The repetition shall be permitted under the standard and the receiving STA(s) would treat it no different than any other channel number.

3.1.2 *Channel Measurement Process*

The measurement of a channel depends on the type of the measuring device, that is, whether it is an AP or a non-AP STA.

3.1.2.1 *AP Channel Measurement*

The channel measurement by the AP does not need to be standardized, as it does not need to report the measurement results to other STAs. However, the AP measurement should be done in such a way that the service disruption be minimized. Additionally, the AP shall be able to perform the same measurements as non-AP STAs described in below. Note that in the infrastructure BSS, the AP should be ready to receive frames all the time unless it is transmitting a frame. This can be achieved by measuring the channel during a contention free period (CFP). By announcing the *aCFMaxDuration*, which is larger than the value needed to support the Quality-of-Service (QoS) agreed with the associated STAs, the AP can have some residual time after completing all the scheduled polls/transmissions within a CFP. During this residual period, the AP can measure the current channel and/or other channels. Another possible way for the AP to measure the channel is to use the Clear to Send (CTS) frame. That is, by sending a CTS frame with self-address as the receiver address (RA), the AP can force all the STAs, which receive this CTS frame, to keep silent during the specified period. Then, during this specified period, the AP can measure the channel condition.

3.1.2.2 *Non-AP STA Channel Measurement*

The channel measurements by non-AP STAs will be in three forms: (1) detection of other BSSs, (2) measurement of Clear Channel Assessment (CCA) busy periods, and (3) measurement of received signal strength statistics. The details are presented in the following subsections.

3.1.2.2.1 Detection of Other BSSs

The most basic measurement is to detect existing BSSs in the requested frequency channel. This can be done easily by re-using the functions from the "scan" service, i.e., MLME-SCAN.request/confirm. As part of this detection, the STA shall detect whether the detected BSS(s) are 802.11e-enabled QBSS. Furthermore, in case when BSS(s) were detected, the STA shall also specify if frames with "To DS" and/or "From DS" fields set as well as beacon frames were received. The STA shall also specify if at least one valid PLCP Preamble was detected without a valid SIGNAL field being subsequently detected. This could indicate the existence of alien systems with a similar PHY to IEEE 802.11a.

3.1.2.2.2 Measurement of CCA Busy Periods

The STA shall also keep track of the CCA busy periods in order to report back the fractional period during which the CCA was busy out of the whole measurement duration. Note that CCA shall be indicated busy by (1) the start of a valid OFDM transmission at a receiver level ≥ -82 dBm with a probability > 90% within 4 usec, and (2) any signal above –62 dBm. Therefore, the fractional period can be non-zero even when no BSS is detected.

The statistics of the received signal strength shall be measured. When no BSS is detected in the frequency channel, the received signal strength is measured by the instantaneous energy level sample at the antenna and when BSS(s) are detected, the received signal strength is measured from the PLCP preamble of each received frame.

A STA shall attempt to determine the characteristics of the periodic burst by keeping track of the following information. A STA shall keep track of the number of consecutive CCA busy periods observed where each busy period is defined as CCA busy indication during one slot time. Similarly, a STA shall keep track of non-zero interval in Slot Times between the successive busy periods. If these two parameters consecutively match, with a tolerance of 10% (or TBD), then the detected signal shall be labeled as periodic and reported as such. The two associated parameters shall also be reported.

3.1.3 *Measurement Report from STAs*

After completion of a channel measurement, the STA, which was requested to measure the frequency channel(s), reports the result to the AP via the channel measurement report frame defined in Section 3.5.2. This frame may be transmitted upon being polled by the AP during a contention free period (CFP) via PCF or during the contention period (CP) via HCF or during the contention period (CP) via (E)DCF. The STA shall attempt to send the frame to the AP by the time determined from the Report Time Limit field in the channel measurement request frame.

3.2 *Decision Making by AP*

After hearing back from STAs, the decision whether to move out of the current channel or not should be made by the AP and that decision is implementation-dependent. The decision will involve the three factors: (1) whether to move or not, (2) to which channel if it decides to move, and (3) when to move. In order to determine whether to move or not, the AP will have to compare the status of other channels with that of the current channel in terms of STAs' measurement reports as well as its own measurements. The channel switch instant should be affected by the status of sleeping STAs since it is desired to inform all the STAs within the BSS of the channel switch decision and it should also minimize impact on QoS and other traffic.

3.3 *Channel Switch Announcement by AP*

Once the AP determines to switch the frequency channel, it must announce it to STAs in the BSS. The announcement is made via beacon transmissions, that us, a new channel switch announcement information element, defined in Section 3.5.6.1. The AP will transmit beacon frames with the information several times indicating when and to which channel the STAs should jump before the channel switch moment. If a STA misses all these frames, which may happen due to the radio environment, it will be disconnected from the AP after the AP has moved into the new channel. Then, the STA will have to re-associate with the AP by scanning all the channels.

3.4 *Switch into New Channel*

The movement into a new channel should be as simple as changing the carrier frequencies of 802.11a OFDM PHY. Based on the channel switch announcement information, at the scheduled TBTT, all STAs including AP change their channel. The actual channel switch in each STA can be achieved by changing PHY MIB dot11CurrentFrequency using PLME SAP primitives PLME-SET.request (MIBattribute, MIBattributevalue) and PLME-SET.confirm (status, MIBattribute). The channel switching delay should not be long. A maximum switching time will be TBD.

3.5 *Proposed Frames and Information Elements*

We define two new management frames as well as a number of new information elements, which are used in conjunction with the defined management frames, beacon, and probe response frames.

3.5.1 *Channel Measurement Request Frame*

This is a management frame transmitted by the AP to a STA, which is associated with the AP, to request the measurement of specific frequency channel(s). The reception of the channel measurement request frame is acknowledged via a regular ACK frame (during the CP) or a (QoS) CF-ACK (during the CFP) if it has a unicast destination address. The channel measurement request frame is defined using the generic action request frame with the type '00' and subtype '1101', which is being defined by TGe [8]. The format of the channel measurement request frame body is shown below.

octets: 1	1	1	1	6-2300

Category Code (4)	Action Code (0 or 2n, i.e., any even number)	Activation Delay	Dialog Token	Channel Measurement Method element

Figure 3 Channel measurement request frame body

The action code is proposed to be zero, but it can be any even number. This needs to be determined in coordination with TGe.

The activation delay is an implementation-specific value, which is greater than zero. The measurement requests received are processed after the specified number of TBTTs have occurred (e.g. an activation delay of 1 delays the measurement until after the next TBTT, and activation delay of 2 delays the action until after the second TBTT, etc.).

The Dialog Token field is a single octet whose value is adjusted by the AP. The value is copied from each channel measurement request frame into the corresponding channel measurement report frame defined in the following.
The channel measurement method element can be one of two forms: basic channel measurement method and CFchannel measurement method information elements as described in Sections 3.5.6.2 and 3.5.6.3, respectively.

3.5.2 *Channel Measurement Report Frame*

This is a management frame transmitted by a STA to the AP, which the STA is associated with, to report the measurement of requested frequency channel(s). The reception of the channel measurement report frame is acknowledged via a regular ACK frame (during the CP) or a (QoS) (+)CF-ACK (during the CFP). The channel measurement report frame is defined using the generic action response frame with the type ‘00’ and subtype ‘1101’, which is being defined by TGe [8]. The format of the channel measurement report frame body is shown below.

octets: 1	1	1	1	4-2300
Category Code (4)	Action Code (1 or 2n+1 from the definition of the request frame)	Action-specific Status	Dialog Token	Channel Measurement Report element

Figure 4 Channel measurement report frame body

A channel measurement report frame can be transmitted without being requested by the AP via the channel measurement request frame. In this case, the value of Dialog Token will be set to zero (or TBD).
The Status field is a single octet, which indicates the completion status of the channel measurement request.

Value	Status
0	The requested measurement completed successfully
1	Reserved status for the generic action response frame specifying “Unrecognized Action code”
2	Reporting the channel measurement without being requested
3-255	Reserved

3.5.3 *Beacon and Probe Response Frames*

The beacon frame and probe response frames are augmented by a new information element, which is Channel Switch Information element defined in the following section.

Order	Information	Notes
13	Channel Switch Announcement	

Table 11 Modification to Beacon for Channel Switch information

Order	Information	Notes
12	Channel Switch Announcement	

Table 12 Modification to Probe Response for Channel Switch information

3.5.4 *Association and Reassociation Request Frames*

The association request and reassociation request frames are augmented by a new information element, which is Supported Channels Information Element defined in the following section.

Order	Information	Notes
5	Supported Channels	

Table 13 Modification to Association Request for Supported Channels Information

Order	Information	Notes
6	Supported Channels	

Table 14 Modification to Reassociation Request for Supported Channels Information

3.5.5 *Capabilities Information Field*

We propose to define bits 11 and 12 in capability information fixed field as follows:

- TPC: APs and STAs set this bit to specify its capability of TPC. This capability implies that a STA can understand the TPC-related frames and information.
- DFS: STAs set this bit to specify its capability of DFS. This capability implies that a STA understand all the DFS-related frames and information, and can perform the channel measurements and reports.

An 802.11h-compliant STA or AP shall set these two bits.

Bits: 0	1	2	3	4	5	6	7	8	9	10	**11**	**12**	13	14	15
ESS	IBSS	CF-pollable	CF-poll request	Privacy	Short Preamble	PBCC	Channel Agility	QoS	RESERVED	Bridge Portal	**TPC**	**DFS**	RESERVED	RESERVED	Extended Capability

3.5.6 *New Information Elements*

We define the following new information elements in conjunction with the proposed DFS mechanism.

Information Element	Element ID
Channel Switch Announcement	38
Basic Channel Measurement Method	39
CF Channel Measurement Method	40
Channel Measurement Report	41
Supported Channels	42
Reserved	43 - 255

Table 15 New information element IDs

3.5.6.1 *Channel Switch Announcement element*

The Channel Switch Announcement element contains two fields: Channel To Switch and Channel Switch Count.

Octets: 1	1	1	1
Element ID (38)	**Length** (2)	**Channel To Switch**	**Channel Switch Count**

Figure 5 Channel Switch Announcement information element format

Channel To Switch indicates the number of the frequency channel to move.
Channel Switch Count indicates how many beacons (including the current beacon frame) appear before the channel switch of the BSS happens.

3.5.6.2 *Basic Channel Measurement Method information element*

The Basic Channel Measurement Method element contains two fields: Measurement Duration and Channel Numbers.

Octets: 1	1	2	1 – n	1
Element ID (39)	**Length** (4 – n+3)	**Measurement Duration**	**Channel Numbers**	**Report Time Limit**

Figure 6 Basic Channel Measurement Method information element format

Measurement Duration (≥ 0) indicates the time duration, in the number of time units (TUs), which the requested STA spends for the measurement of each channel. Measurement Duration zero is allowed with the one-octet Channel Numbers field, which is equal to the current channel number.

Channel Numbers indicate a set of channels to be measured, in which each octet specifies a channel number. The maximum length will differ depending on the number of available channels in the corresponding specific regulatory domain.

Report Time Limit (> 0) indicates the time duration, in the number of TBTTs, which the requested STA should report the measurement results back to the AP after the frequency channel measurement.

3.5.6.3 *CF Channel Measurement Method element*

The CF Channel Measurement element contains four fields: Measurement Duration, Measurement Offset, Non-Measurement Duration, and Channel Numbers.

Octets: 1	1	2	1	1	1 – n	1
Element ID (40)	**Length** (6 – n+5)	**Measurement Duration**	**Measurement Offset**	**Non-Measurement Duration**	**Channel Numbers**	**Report Time Limit**

Figure 7 CF Channel Measurement Method information element format

Measurement Duration (> 0) indicates the time duration, in number of TUs, which the requested STA spends for the measurement of each channel.

Measurement Offset and Non-Measurement Duration represent the time period out of each CFPRI, which the requested STA should not be away from the current channel for the measurement of a remote channel. For example, during a CFPRI time frame [0, CFPRI], starting from a TBTT, at which a CFP starts, the STA will be away from the current channel for the measurement of a remote channel except for the period [CFPRI * MO / 256, CFPRI * (MO + NMD) / 256], where MO is the value of Measurement Offset and NMD is the value of Non-Measurement Duration, respectively.

Report Time Limit (> 0) indicates the time duration, in the number of TBTTs, which the requested STA should report the measurement results back to the AP after the frequency channel measurement.

3.5.6.4 *Channel Measurement Report Information Element*

Octets: 1	1	1	1
Element ID (41)	**Length** (2 – 2+10*n)	**Power Level Adjustment**	**Own Beacon RSSI**

Octets: 1	1	1	1	2	4
Channel Number *1*	**Measurement Summary**	**CCA Busy Fraction**	**CCA Busy Duration**	**CCA Busy Interval**	**RSSRI Statistics**

...
...

Octets: 1	1	1	1	2	4
Channel Number *n*	**Measurement Summary**	**CCA Busy Fraction**	**CCA Busy Duration**	**CCA Busy Interval**	**RSSRI Statistics**

Figure 8 Channel Measurement Report information element

Length fields can represent from 2 to 2+10**n* depending on the number *n* of the frequency channels to report the measurements about.

CCA Busy Duration and CCA Busy Interval fileds are valid only if *Periodicity* bit is set in the Measurement Suummary filed. When the bit is not set these fields will be set to zeros. If the *Periodicity* bit is set then CCA Busy Duration represents the number of consecutive time slots the CCA busy was detected and the CCA Busy Interval field represents the time interval in time slots of the repeating CCA Busy indicators. Power Level Adjustment is copied from 'Power Level Adjustment' information element in the beacon, which was received from the current AP most recently before the channel measurement.

Own Beacon Received Signal Strength Indicator (RSSI) field is determined as a function of the received signal strength, which is the energy observed at the antenna used to receive the PLCP preamble, of the particular beacon, as shown in
Table 16. Then the measurement duration of the corresponding channel measurement request frame was zero, both Power Level Adjustment and Own Beacon Received Signal Strength fields are only included in the channel measurement report element. This can be used in conjunction with the transmit power control (TPC) of the particular STA.

Received Signal Strength Indicator (RSSI)	Energy Observed at the Antenna (dBm)	Tolerance (dB)
0 ≤ RSSI ≤ 7	RESERVED	
RSSI = 8	< -91	+8
9 ≤ RSSI ≤ 70	RSSI – 100	±8 for RSSI = 9 ±7 for RSSI = 10 ±6 for RSSI = 11 ±5 for 12 ≤ RSSI ≤ 59 ±6 for 60 ≤ RSSI ≤ 66 ±7 for 67 ≤ RSSI ≤ 68 ±8 for 69 ≤ RSSI ≤ 70
RSSI = 71	> -30	-8
72 ≤ RSSI ≤ 255	RESERVED	

Table 16 Received Signal Strength Indicator (RSSI) from energy observed at the antenna

Sets of quartet (Channel Number, Measurement Summary, CCA Busy Fraction, RSSRI Statistics) follow next. The number of channels, which was requested to measure via the channel numbers field in the corresponding channel measurement request frame, determines the number of the sets.
One-octet measurement summary field is represented as follows:

Bits: 1	1	1	1	1	1	1	1
BSS	QBSS	Periodicity	Beacon	Foreign PLCP Header	To DS	From DS	RES

Each field is defined as follows:

- BSS: specifies that at least one valid MAC Header was decoded for the measured frequency channel.
- QBSS: specifies that at least one BSS is running in QBSS. This bit can be set only if the STA reporting is 802.11e MAC enabled.
- Periodicity: This bit specifies that 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 Interval are identical within a tolerance of 10% (or TBD).
- Beacon: specifies that at least one beacon was received during the measurement.
- ForeignPLCPHeader: specifies that at least one PLCP Preamble was detected, but no valid SIGNAL field was subsequently detected.
- To DS: specifies that at least one frame with 'To DS' field set was received during the measurement.
- From DS: specifies that at least one frame with 'From DS' field set was received during the measurement.

CCA Busy Fraction field specifies the fractional period when the CCA was busy out of the whole measurement time in the specific frequency channel. It is calculated as

CCA Busy Fraction = Ceiling (255 × [CCA Busy Period] / [Total Measurement Duration])

Depending on the value of the 'BSS' field, the following 4-octet Received Signal Strength Range Index (RSSRI) Statistics field will represent two different measurement results/indicators. When BSS field is set, i.e., one, it represents the statistics of the energy level measured during the reception of the PLCP preamble for each received frame, while when it is not set, i.e., zero, it represents the statistics of the instantaneous energy level observed at the antenna. It is sampled periodically with the period 32 usec or TBD.
Each octet of the RSSI Statistics field is represented as follows:

Bits: 3	5
RSSRI	Density

3-bit Received Signal Strength Range Index (RSSRI) is defined as shown in Table 17 as a function of:

(1) the energy level observed during the reception of the PLCP preamble of a received frame in case of BSS field set, i.e., one, or
(2) an instantaneous energy level observed at the antenna in case of BSS field not-set, i.e., zero.

The STA during the frequency channel measurement keeps track of the number of measured samples corresponding to each RSSRI. 5-bit Density field is defined by

Density (RSSRI) = Ceiling (31 × [Number of samples corresponding to the RSSRI] / [Total Number of Samples])

Four RSSRI's with the largest Density values will be chosen, and will be included in RSSRI Statistics field.

Received Signal Strength Range Index (RSSRI)	Energy Observed at the Antenna (dBm)	Tolerance (dB)
0	Energy < -87	+5
1	-87 < Energy < -82	±5
2	-82 < Energy < -77	±5
3	-77 < Energy < -72	±5
4	-72 < Energy < -67	±5
5	-67 < Energy < -62	±5
6	-62 < Energy < -57	±5
7	-57 < Energy	-5

Table 17 Received Signal Strength Range Indicator (RSSRI) from energy observed at the antenna

3.5.6.5 *Supported Channels Information Element*

Octets: 1	1	7	Notes
Element ID (42)	**Length** (7)	**Supported Channels**	

Table 18 Supporete Channel information element

Each bit in 7-octet Supported Channel field correponds to a channel number. Bit 0 corresponds to channel number 1 and the bit 199 corresponds to channel number 200. The bits 200-223 shall be reserved and set as zeros. A particular bit is set when the corresponding channel number is supported by the STA.

4 Conclusion

The marketplace for 5 GHz broadband wireless systems will likely be very competitive in a few years with products built to international standards and proprietary products built for specialized markets. The range of applications for broadband wireless includes: homes, enterprise networks, and operator WLANs (to name a few). While DFS and TPC mechanisms are required as defined in ERC/DEC (88) 23, the goal of this proposal is to meet the requirements and also enhance the performance of IEEE802.11 5 GHz wireless LANs. The DFS and TPC mechanisms defined here will aid in efforts to improve capacity, improve quality of service (in IEEE802.11e devices), and extend the battery life of portable wireless devices. By focusing not only of the PAR, but also on how to enhance IEEE802.11 5 GHz WLANs we ensure that our WLANs will have the flexibility to adapt to a variety of indoor and outdoor deployment scenarios.

5 References

[1] Gerard G. Cervelló, Sunghyun Choi, Stefan Mangold, and Amjad Soomro, "Dynamic Channel Selection (DCS) Scheme for 802.11," IEEE 802.11-00/195r2, September 2000.

[2] IEEE, “Reference number ISO/IEC 8802-11:1999(E) IEEE Std 802.11, 1999 edition. International Standard [for] Information Technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific Requirements- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications,” 1999.

[3] ERC, “Study of the frequency sharing between HiperLANs and MSS feeder links in the 5 GHz band,” ERC Report 67.

[4] ERC, “Compatibility Studies Related To The Possible Extension Band For HiperLAN at 5 GHz,” ERC Report 72.

[5] ERC/DEC/(99)23. ERC Decision of 29 November 1999 on the harmonized frequency bands to be designated for the introduction of High Performance Radio Local Area Networks (HiperLANs).

[6] Greg Chesson and Bill McFarland, “Atheros Communications DFS/TPC Proposal,” IEEE 802.11-00/270, September 2000.

[7] IEEE 802.11, “Supplement to STANDARD [for] Information Technology-Telecommunications and information exchange between systems-Local and metropolitan area networks-Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5 GHz Band,” IEEE Std 802.11a-1999, September 1999.

[8] IEEE Std 802.11e QoS/D1 “Draft Supplement to STANDARD FOR Telecommunications and Information Exchange Between Systems – LAN/MAN Specific Requirements- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service”, IEEE Std 802.11e/D1, March 2001.

[9] Steven Gray and Venkatesh Vadde, “Throughput and Delay Performance of DCF with Variable Transmit Power,” IEEE 802.11-01/227, May 2001.

[10] IEEE Std 802.11d/D3, “Draft Supplement to STANDARD FOR Telecommunications and Information Exchange Between Systems-LAN/MAN Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Specification for Operation in Additional Regulatory Domains", March 2001.

[11] Andrew Myles, David Skellern and Peter Ecclesine, “Independent TPC (ITPC) and Comments on DCS,” IEEE 802.11-01/219, April 2001.