Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Message Specification for Cognitive Radio Systems operating as Frequency Division Duplexing (FDD) IEEE 802.16h Networks**
Date Submitted	**2005-11-08**
Source(s)	John Sydor, Shanzeng Guo Communication Research Center 3701 Carling Ave Ottawa, ON, Canada, K8H 8S2 Voice: (613) 998-2388 Fax: (613) 998-4077 {jsydor, sguo}@crc.ca
Re:	Call for Contribution, “IEEE 802.16’s License-Exempt (LE) Task Group”, 2005-10-17 Item 4.
Abstract	This proposal proposes that radio packets (frames) be tagged with both origin and emission information pertaining to the IEEE 802.16h radio terminal generating the packets. When tagged information is received by terminals or systems as co-channel interference, the tagged information allows the interfered-with terminal to take immediate local action or initiate an IP response to limit the interference. The local response could be a change to an adaptive antenna for instance; the IP response can be in the form of an interference message that is generated by the interfered-with network and sent to the interfering network. The contents of the messaging described herein can provide a framework for the type of information that may be useful to keep at the BSIS data base, once it becomes better defined.
Purpose	This document describes the general structure of the messaging needed to support CR for FDD and TDD operation within IEEE 802.16h. It also provides details on the type of basic electromagnetic environment information that CR systems will need as they adaptively undertake co-channel interference mitigation.
Notice	
Release	
Patent Policy and Procedures	

Message Specification for Cognitive Radio Systems operating as Frequency Division Duplexing (FDD) IEEE 802.16h Networks

John Sydor, Shanzeng Guo
Communication Research Center, Ottawa, ON, Canada

1. Introduction

This contribution is a refinement from previous contribution in the working document IEEE802.16h-05/022. The basic principle outlined is that RF emissions should be tagged so that all demodulated interference can be identified, and its origin located. Additionally, it is proposed that the tagging include information that characterizes the specific electromagnetic emission characteristics of the interferer.

2. Message Specification

2.1 DCD – Expanded message

[***This section is to replace the whole of section 15.6.8.2.2 of IEEE802.16h-05/022***]

DCD messages are sent by base station to multiple subscribers associated with that base station. It is assumed that the base station has a unique IEEE 802.16 identity (BS_ID) and a Network Operations Center (NOC) that controls the base station and its associated subscriber stations' operation. The NOC is presumed to be connected to the TCP/IP network, and has a functioning IP protocol stack with an IP address.

Every DCD sent downlink has a BS_ID associated with it. This is thus a de facto tag to the downlink frame, and can be used as an interference identification tag.

The expanded DCD message sent by the base station contains additional information (Table 1) pertinent to the cognitive radio processing. The expanded DCD contains radio emission information particular to the base station generating it. In the IEEE 802.16h operation, the expanded DCD, will be sent every ~ 10 (TBD) seconds. The CR processor, either in within the interfered-with SS or its host NOC, to take avoidance actions aimed at interference mitigation once the expanded DCD is demodulated as interference.

Name	Type (1 byte)	Length (bytes)	Value	Phy Scope
NOC IPv4 Address	18	4	The Network Operation Center IP address to which the base station is associated, and which likely contains the CR processor responsible for the base station and its associated SS.	All

NOC IPv6 Address	19	16	The Network Operation Center IP address to which the base station is associated, and which likely contains the CR processor responsible for the base station and its associated SS.	All
RF antenna sector ID	20	1	The RF antenna sector identifier for a base station. 1 – 255 for FDD only 0 – reserved for TDD only	FDD only
BS_GPS	21	6	GPS coordinates of the base station (optional) 2 MSB: Latitude 2 LSB: Altitude 2 Middle bytes: Height	All
BS_ANT_HT	22	2	Height of the Base Station emission antenna in meters above sea level.(optional)	All
BS_ANT_WDTH	23	2	In degrees, width of –3 dB beam as measured in the azimuth plane (optional)	All
BS_ANT_DIR	24	2	Azimuth measurement in degrees (optional) wrt true north	All
UL_RF	25	4	Uplink channel assignment in KHz associated with this downlink channel (FDD-optional)	FDD only
RF_REUS	26	1	Information on sectors pertaining to this GPS location (TBD-Optional)	FDD only

Table 2 Content of Expanded DCD message (addition to Table 358 in IEEE 802.16 2004)

The reception of the expanded DCD provides the CR processor of the interfered-with SS with a number of options when determining a response or other action to mitigate interference. Some of these approaches can be as follows:

(1) The GPS coordinates will allow calculation of lineal distance between the source of interference and the interfered-with subscriber station. Antenna heights, beamwidth, and main lobe direction of the interfering antenna and its EIRP will allow

calculation of link budget parameter leading to derivation of a path loss exponent (PLE) for the link. Multiple readings of expanded DCDs allow calculation of the variance and mean PLE for the interference propagation path. Such calculations can lead to the estimation of co-channel interference noise floors that are below the demodulation threshold of the receivers. The results can lead to a more accurate estimate of the capacity of the interfered-with link and result in corrective action such as changes to the downlink EIRP of the interfered-with link and modulation format (these in order to take advantage of the S/(No+Io); Io being the random variable associated with the co-channel interference).

(2) Adaptive antenna processes on the interfered-with link can use the complete DCD information to support null steering and differentiate line of sight propagation from that due to strong discreet multipath. GPS coordinate would allow much quick convergence of adaptive antenna algorithms or facilitate the distribution of the limited number of nulls produced by such antenna. Such processing could be undertaken independently at the SS, especially if it uses adaptive antenna processing.

(3) Complete DCD information provides the interfered-with SS and its NOC with information on the size of the coverage area created by the interfering BS. This is useful information for future altruistic-spectrum sharing negotiations between interfering but independent wireless networks that may negotiate on the basis of coverage area per hertz of available bandwidth.

(4) The extraction of a NOC IP address allows the CR to associate interference with a specific network. In the simplest response the interfered-with SS will generate a SS_CCID_IND message to its own NOC indicating the existence of downlink interference, and in the SS_CCID_IND give the IP identity of the interference.

(5) The RF antenna ID within a base station is used to identify the co-channel interference caused by another RF antenna sector with the same RF frequency. This identification facilitates CCI control for multiple-frequency reuse using spatial electromagnetic isolation (by low side lobe antennas) within the same cell.

The DCD (standard and expanded) are transmitted with every downlink IEEE 802.16h downlink frame as the BS_ID found in the DL_MAP. The DCD is transmitted by both FDD and TDD systems. As such, given the synchronous nature that the Cognitive Radio system will likely have, the DCD will likely demodulated as interference regardless of the duplexing scheme.

Any SS receiving a downlink frame as interference will be able to classify the received frame as interference because of the presence of a foreign BS_ID in the DL_MAP message. The CR processor in a SS can count the frequency of interference intervals and conduct classification of interference sources. The CR processor associated with the interfered-with SS can count the packet interference instances and determine the level of deleterious interference they cause. Interference would be associated with specific BS and their NOCs, and there could be multiple sources for overlapping networks. Sporadic interference may be ignored if it does not affect the capacity of the SS downlink by more than 1%. Deleterious interference may be classified as causing capacity to be reduced by >10%. The ability to classify the interference also allows the CR processor to differentiate between types of interference. Such differentiation can allow the application of linear predictive algorithms or classification strategies to predict instances of non-interference. The important issue to realize in the above scenario that regardless of the synchronization and interference avoidance that occurs between co-located ad-hoc networks, there is the very real possibility of sporadic interference occurring because of transient propagation phenomena can occur may be too difficult, or unwarranted, to control using network level CR techniques. Such control may be more easy to undertake at the individual SS; which as has been pointed out, may ultimately use sophisticated antenna and signal processing techniques.

2. 2 SSURF – Uplink Messages

[***This section is to replace the whole of section 15.6.8.2.3 of IEEE802.16h-05/022***]

The subscriber station uplink radio frequency (SSURF) message shall be a new MAC message for IEEE 802.16h. This message is periodically broadcasted by SS as uplink tags, but could also contain the RF emission and link reception characteristics of the subscriber station.

Upon reception of this message, BS will stamp the message based on the arrival time and generate a SS_CCID_IND trap message if its base station ID is different from the base station Id in this packet, or its RF reuse sector ID is different from the one in the received packet. SSURF message format is as follows:

Syntax	Size	Notes
SSURF_Message_Format ( ) {		
Management Message Type =50	8 bits	
Downlink channel ID	8 bits	
TLV Encoded information for the overall channel	Variable	TLV specific
}		

The primary reason for the complete SSURF message is to provide the base station with information regarding the RF reception performance of its associated subscriber terminals. Such information would allow CR system at the NOC to make decisions on the link performance, and facilitate adjustments, including downlink load balancing, across the network.

The mean received signal level and its variance provided by the SS in the SSURF would give the NOC CR system an understanding of the propagation environment that the subscriber station is being influenced by. High variance in RSSI should result in correlated variances in BER. High variance in CCIR could also be correlated with variances in BER. A CR processor will be able to use such information differentiate the process leading to BER variations, determine the existence of sub-demodulatable interference, and determine the “white space” noise floor and its characteristics. The CR could then change aspects of the downlink power control regime for the SS, it could change the received demodulation, or in concert with PSD measurements (See PSD_REQ), make decisions on channel occupancy, amongst other decisions.

The complete SSURF when received as interference would provide the interfered-with base station’s NOC with altruistic information concerning the propagation stability of the interference link versus the established link between the interfering subscriber and its base station. Link budget calculations could be performed indicating difference between the operational and interference propagation paths. More complex analysis with interference measurements from a number of terminals and directions would for example determine path loss profiles of two overlapping, but independent co-channel coverage areas. Such information could provide the basis for competing NMSs for coverage area/spectrum division negotiations.

The accuracy of such estimations will depend on the content of the complete SSURF message. It is realized that many simple terminals will not be able to have complete information fields in their SSURF, but even simple information such as range and EIRP may be enough to make a significant mitigation of co-channel interference.

SSURF TLV encoding are provided in the following table.

Name	Type (1 byte)	Length (bytes)	Value	PHY Scope
SS_ID	1	6	Subscriber station ID transmitting SSURF, i.e the MAC address of SS	

NOC_IPv4	2	4	NOC IP address to which SS is associated	
NOC_IPv6	3	16	NOC IP address to which SS is associated	
EIRP	4	1	Nominal EIRP of SS or the per burst EIRP	
D_time	5	1	Interval in secs for the measurements, over which N measurement samples were taken.	
M_RSSI	6	2	Mean RSSI of downlink packets received over measurement interval, ie N samples. As per Sec 8.4.11 of IEEE Std 802.16-2004	
Var_RSSI	7	2	The variance of the RSSI as per Sec 8.4.11 of IEEE Std. 802.16-2004	
M_CCIN	8	2	Mean Cochannel to interference (CCI) as per Sec 8.4.11	
Var_CCIN	9	2	Variance in the CCI as per Sec 8.4.11	
M_BER	10	4	Mean Bit Error Rate	
Var_BER	11	4	Variance in the BER	
SS_ANT_HT	12	2	Subscriber antenna height (optional) meters above sea level	
SS_ANT_WDTH	13	2	Subscriber antenna width degrees (-3 dB)	
SS_ANT_DIR	14	2	Subscriber antenna main lobe direction wrt true north (degrees azimuth)(optional)	
SS_GPS	15		GPS location of subscriber (optional)	
SS_RNG	16	2	Range of SS from base station (meters)	
SS_ANT_PAR_LST	17	1	Antenna parameter list indication of adaptive, horizontal or vertical polarization , diversity element number.	

SS_MOD	18	1	Downlink modulation format of SS	

Table 4 Content of the SSURF message

2.3 Uplink MAC header change

In order to detect co-channel interference effectively, the base station identifier field is added in the uplink MAC header. The purpose of the basic SSURF is to tag every uplink RF emission by the SS. In the event that the uplink transmission is received by a foreign (interfered-with) base station or another RF antenna sector within the same base station, that base station will be able to eliminate the interference packet from its received data path. Furthermore, the CR processor in the interfered-with base station will be able to undertake the following operations:

(1) Counting the frequency of interference and simple classification of interference sources. The CR processor associated with the BS can count the packet interference instances produced by specific interfering subscriber terminals and determine the level of deleterious interference they cause. This is similar to the process to the SS undertakes with the DCD.

(2) The abstraction of the NOC IP address from SSURF allows the CR in the interfered-with base station to associate specific interfering subscriber with the network to which that subscriber is associated. In its simplest response the CR within the BS would produce a BS_CCID_IND message directed its NOC, providing information that would facilitate a response by its NOC to the interfering NOC.

The uplink MAC header will defined as follows:

Syntax	Size	Notes
Uplink MAC Header {		
HT	1 bits	0 = Generic MAC header 1 = Bandwidth request
EC	1 bits	If HT=1, EC=0
If (HT=0) {		
Type	6 bits	
Reserved	1 bit	Shall be set to zero
CI	1 bit	
EKS	2 bits	
Reserved	1 bit	Shall be set to zero
LEN	11 bits	
}		
Else {		
type	3 bits	
BR	19 bits	
}		
CID	16 bits	
HCS	8 bits	

Base station ID	48 bits	
}		

2.3 SS_CCID_IND

[***This section is to replace the whole of section 15.6.1.31 of IEEE802.16h-05/022***]

This is a message sent by a SS to its CR_NOC when co-channel interference is detected at SS. This message shall contain the following information to determine the source of co-channel interference experienced by the victim SS. This information is extracted from the expanded DCD message sent by a base station.

SS_CCID_IND TLV encoding are provided in the following table

Name	Type (1 byte)	Length (bytes)	Value (Variable length)	PHY scope
CCI source	1	6	Co-channel interfering base station ID	All
NOC IPv4 Address	2	4	The Network Operation Center IP address to which the interfering base station is associated, and which likely contains the CR processor responsible for the base station and its associated SS.	All
NOC IPv6 Address	3	16	The Network Operation Center IP address to which the interfering base station is associated, and which likely contains the CR processor responsible for the base station and its associated SS.	All
RF antenna sector ID	4	1	The RF antenna sector identifier for the interfering base station. 1 – 255 for FDD only 0 – reserved for TDD only	
BS_GPS	5	6	GPS coordinates of the interfering base station 2 MSB: Latitude 2 Middle bytes: Height 2 LSB: Altitude	All
BS_ANT_HT	6	2	Height of the interfering Base Station emission antenna in meters above sea level.	All
BS_ANT_WDTH	7	2	In degrees, width of –3 dB beam as measured in the azimuth plane of interfering base station antenna	All
BS_ANT_DIR	8	2	Azimuth orientation in degrees wrt true north, of interfering antenna.	All

EIRP	9	1	Either the per-burst EIRP or the average EIRP of the interfering emitter antenna. This information is contained in the simple DCD	All
UL_RF	10	4	Uplink channel assignment in KHz associated with this downlink channel (FDD- optional)	
RF_REUSE	11		Information on sectors pertaining to this GPS location (TBD-Optional)	FDD only
CCI victim	12	7	First 6 MSB: subscriber station ID Last byte: RF antenna sector ID. 1 - 255 0 reserved for TDD.	All

None of above TLV in this message is repeatable.

2.4 SS_CCID_RSP

[***This section is to replace the whole of section 15.6.1.32 of IEEE802.16h-05/022***]

This is a message sent to the victim SS by its CR-NOC. It is used to set the emission or reception qualities of the specified SS. This message is usually sent in response to a SS_CCID_IND message generated by the interfered-with SS. Conceivably, other messages embedded withing the current IEEE 802.16-2004 standard can be used to initiate similar changes (TBD).

SS_CCID_RSP TLV encoding are provided in the following table

Name	Type (1 bytes)	Length	Value (Variable length)	PHY scope
SS-ID	1	6	Subscriber Identifier	All
EIRP	2		EIRP of receiving SS -127 to +127 dBm Bit 7: 0 - positive value 1 - negative value	
Downlink RF	3	4	Downlink Radio Frequency (KHZ)	FDD only
Uplink RF	4	4	Uplink Radio Frequency (KHZ)	FDD only
New BS-ID	5	6	New Base station that can serve this SS. SS should register with the new BS.	
Adaptive antenna configuration	6	1	Antenna parameter list Bit 0: 0 - not adaptive 1 - adaptive Bit 1: 0 - Horizontal (polarization) 1 - Vertical (polarization) Bit 3 diversity Bit 4-7 AAS (TBD)	All
CNTI_SS_TBD	7	4	Timing information (TBD) for SS	

None of above TLV in this message is repeatable.

2.5 BS_CCID_IND

[***This section is to replace the whole of section 15.6.1.33 of IEEE802.16h-05/022***]

This is a message sent by an interfered-with BS to its CR_NOC when co-channel interference is detected. This message shall contain the following information to determine the source of the co-channel interference and its RF emission characteristics. This information is extracted from the SSURF messages sent by the interfering SS.

BS_CCID_IND TLV encoding are provided in the following table

Name	Type (1 byte)	Length (bytes)	Value (Variable length)	PHY scope
SS_ID	1	6	Interfering SS ID transmitting SSURF, i.e the MAC address of SS	
BS_ID	2	6	Base Station ID to which interfering SS is associated	
NOC_IPv4	3	4	NOC IP address to which interfering SS is associated	
NOC_IPv6	4	16	NOC IP address to which interfering SS is associated	
EIRP	5	1	Nominal EIRP of interfering SS or the per burst EIRP	
D_time	6	1	Interval in secs for the measurements, over which N measurement samples were taken.	
M_RSSI	7	2	Mean RSSI of downlink packets received over measurement interval, ie N samples. As per Sec 8.4.11 of IEEE Std 802.16-2004. Of interfered-with SS	
Var_RSSI	8	2	The variance of the RSSI as per Sec 8.4.11 of IEEE Std. 802.16-2004	
M_CCIN	9	2	Mean Cochannel to interference (CCI) as per Sec 8.4.11, at the interfering SS, as experienced on its desired link	
Var_CCIN	10	2	Variance in the CCI as per Sec 8.4.11 at interfering SS, as experience on its desired link.	
M_BER	11	4	Mean Bit Error Rate at interfering SS	
Var_BER	12	4	Variance in the BER at interfering SS	
SS_ANT_HT	13	2	Interfering SS antenna height meters above sea level (Optional)	
SS_ANT_WDTH	14	2	Interfering SS antenna beamwidth degrees (-3 dB)	
SS_ANT_DIR	15	2	Interfering SS antenna main lobe direction wrt true north (degrees azimuth) (optional)	

SS_GPS	16		GPS location of interfering SS (optional)	
SS_RNG	17	2	Range of interfering SS from its base station (meters)	
SS_ANT_PAR_LST	18	1	Antenna parameter list indication of adaptive, horizontal or vertical polarization , diversity element number.	
SS_MOD	19	1	Downlink modulation format of interfered with SS	
Base station RF antenna sector ID	20	1	The RF antenna sector identifier for a base station. 1 – 255 for FDD only 0 – reserved for TDD only	
BS_ID_VICT	21	6	ID of BS generating this message; the interfered-with BS ID	

None of above TLV in this message is repeatable.

2.6 BS_CCID_RSP

[***This section is to replace the whole of section 15.6.1.34 of IEEE802.16h-05/022***]

This is a message to set the configuration of the BS. It is sent by the CR_NOC to the BS being changed, and is usually send in response to a BS_CCID_IND message indicating interference from a foreign SS. It shall have the following information:

BS_CCID_RSP TLV encoding are provided in the following table

Name	Type (1 bytes)	Length	Value (Variable length)	PHY scope
BS-ID	1	6	Base station Identifier to receive this message	All
EIRP	2		EIRP of receiving BS - 127 to 127 dBm Bit 7: 0 - positive value 1 - negative value	
Downlink RF	3	4	Downlink Radio Frequency (KHZ)	FDD only
Uplink RF	4	4	Uplink Radio Frequency (KHZ)	FDD only
Adaptive antenna configuration	5	1	Antenna parameter list Bit 0: 0 - not adaptive 1 - adaptive Bit 1: 0 - Horizontal (polarization) 1 - Vertical (polarization) Bit 3: diversity Bit 4-7 AAS (TBD)	All

CNTI_BS_TBD	6	4	CNTI timing changes directed to BS (TBD)	

None of above TLV in this message is repeatable.

2.7 PSD_REQ

[***This section is to replace the whole of section 15.6.1.35 of IEEE802.16h-05/022***]

All co-channel interference that is created cannot necessarily be demodulated or decoded correctly, thereby allowing the extraction of tagged information from interference frames. Additionally, some users of license-exempt spectrum may not comply with any of the IEEE standards and be impossible to identify, for example, Ultra Wide Band transceivers may fall into this category. In the event of this it is useful for a cognitive radio to be able to monitor the LE spectrum to determine available spectrum "white space" and determine sub-detection interference levels. "Snapshots" of spectrum space are useful to CR systems, especially when new base stations or terminals are installed and are searching for unoccupied spectrum.

Because of the bursty nature of the IEEE 802.16h, IEEE 802.11a/b/g, and other packet based systems that will occupy the LE bands, Recording of spectrum PSD levels should be done on a peak hold basis. Provision is made in the message to define the equivalent resolution bandwidth of the measurement. It is recognized that some base stations may have multiple antennas associated with the same BS_ID; provision is made to include measurements from multiple antennas.

Though still TBD at the time of this writing, the spectrum density plot of a base station will likely reside in the CR_NOC or at the shared data base of the BS, where it can be accessed by TBD messaging by other CR_NOCs. The PSD will be recorded as a function of azimuth orientation around the base station, and two perspectives should be (TBD) presented: one PSD vs Azimuth as determined by the BS and another PSD vs Azimuth as determined by the SS associated with the BS.

This is a message to request a BS or SS to sample PSD (power spectrum density) data and send these data back to originator. Since sampling PSD data will take some time, depending on environment, nature of bursty users, the following PSD_RSP response message shall take some time for BS/SS to complete the PSD data sampling and response. A UTC time stamp indicating the time of the PSD measurement needs to be associated with the measurement.

PSDs can be undertaken by the SS during instances found at the end of downlink frames but before the transition gap or they can be undertaken during the CTS interval; for TDD systems. At the BS the measurement can be taken during the uplink interval, again during instances when uplink traffic has ceased but before transition to the downlink frame. A similar routine can be followed by FDD systems. There is the requirement for BS and SS terminal RF synthesizers to be able to synthesized new frequencies in sub millisecond intervals, in order to undertake measurements within the up and downlink frames.

PSD_REQ TLV encoding are provided in the following table

Name	Type (1 bytes)	Length	Value (Variable length)	PHY scope
RF antenna sector ID	1	1	RF Antenna sector identifier. 1 - 255 0 - reserved This value is for base station only.	FDD only

For TDD system, there is no TLV needed for this message.

2.8 PSD_RSP

[***This section is to replace the whole of section 15.6.1.36 of IEEE802.16h-05/022***]

This is a response message from a BS or SS. The resolution bandwidth is scalar, it is used together with X-max and X-min to determine how many PSD values are collected and contained in the this message, X-max is bound of channel frequency, whereas, X-min is the lower bound of channel frequency. The total number of PSD measurements is determined by

$$(X_{\max} - X_{\min})/(resolutionBandwidth) + 1 .$$

Upon reception of this message, CR_NMS will stamp the message based on the arrival time and translate the information into internal format and store it into database for further processing.

PSD_RSP TLV encoding are provided in the following table

Name	Type (1 bytes)	Length	Value (Variable length)	PHY scope
RF antenna sector ID	1	1	RF Antenna sector identifier. 1 - 255 0 – reserved This value is for base station only.	FDD only
Antenna Parameter List	2	1	Antenna parameter list Bit 0: 0 - not adaptive 1 - adaptive Bit 1: 0 - Horizontal (polarization) 1 - Vertical (polarization) Bit 3: diversity Bit 4-7 AAS parameters	ALL
Starting RF frequency	3	4	The lower bound of channel frequency in kilohertz	All
Ending RF frequency	4	4	The upper bound of channel frequency in kilohertz	All
Resolution Bandwidth	5	1	RF Bandwidth unit to measure PSD data	All
PSD measurement	6	1	PSD measurement in dBm unit Range from - 127 to 127 dBm Bit 7: 0 - positive value 1 - negative value	All
CNTI_PSD_S TMP	7	4	TBD Time stamp of the PSD spectrum as a function of UTC time.	

PSD measurement TLV can be repeated in this message.