Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Messaging for Cognitive Radio Systems operating as Frequency Division Duplexing (FDD) IEEE 802.16h Networks.**
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Re:	Call for Contribution, "IEEE 802.16's License-Exempt (LE) Task Group", 2005-06-09 Item 4.
Abstract	The addition of several new (or possible re-use of existing) MAC messages to the IEEE 802.16, will make it possible to have radio packets (frames) tagged with information detailing the emission characteristics and origin of the radio generating the packets. When tagged information is received by other terminals or systems as co-channel interference, a response can be forwarded to cognitive entity that can undertake changes to its network architecture or communicate with a higher level network management system which would initiate a process of interference mitigation. The method can also use CIS database proposed for the TDD IEEE 802.16h option, however there is no direct requirement for a CIS in this proposal.
Purpose	Currently the IEEE 802.16 2004 does not support FDD operation in License-Exempt bands. In the event that this is deficiency is rectified, this document can be used as a general outline for signaling modifications to the IEEE 802.16h that would support cognitive radio (CR) networks and terminals operating in a FDD environment. This document describes the general structure of the messaging needed to support CR and FDD within IEEE 802.16h; a more thorough proposal can be undertaken once FDD becomes part of the IEEE 802.16h standard.
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Messaging for Cognitive Radio Systems operating as Frequency Division Duplexing (FDD) IEEE 802.16h Networks.

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1. Messaging and Radio Network Cognition

This document expands on document IEEE C802.16le-04/03; "Notes on an emission information exchange mechanism for License-Exempt 802.16 Cognitive Radio Networks". The messaging proposal described herein supports FDD cognitive radio networks.

Frequency Division Duplexing (FDD) is a technique in which the transmit and receive frequencies of a subscriber terminal are different. This contrasts with Time Division Duplexing, where the same frequency is used for transmission and reception but during different intervals of time.

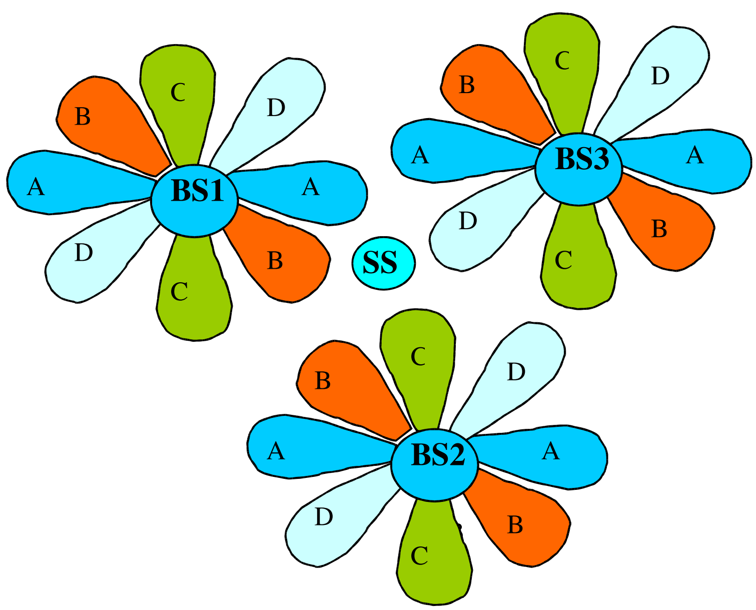
The advantage of FDD for coexistence is that it makes it possible to co-locate basestations within close proximity to each other without the effect of one basestation's transmissions interfering with another base station's reception, providing the base stations follow a policy defining separate downlink and uplink transmission bands. Electromagnetic isolation between base station cells and subscriber terminals is enhanced by using directive antennas with low sidelobes or adaptive antennas. At the low power levels typical of the license-exempt bands FDD becomes a very powerful technique allowing considerable reuse of spectrum. FDD radio circuits tend to be more complex than TDD systems, however with the cost of commodity wireless chipsets, such issues are not as significant as they were in past.

In this proposal it is maintained that by relatively small changes to IEEE 802.16 messaging it becomes possible to support an interference information exchange mechanism between independent but coexisting FDD license-exempt networks. Such a mechanism would allow interfering entities to communicate interference information either between themselves or to another management entity, leading to co channel interference control. This information in the first instance is sensed. It is generated because of the presence of a co-channel interference event. Secondly, sensed co-channel information is tagged: it contains emission characteristics and origin information relating to its source. Interfered-with subscriber terminals and bases stations by both sensing the existence of and knowing the origins of interference can then apply protocols or algorithms that negotiate access to the spectrum and control interference. This can be done, for instance, by changing some emission attribute such as frequency, eirp, direction, polarization, or placement of an antenna null.

Radio terminals and networks that sense and transport interference information, and modify their emission characteristics or network topologies in order to compensate for or mitigate co-channel interference can be broadly termed as cognitive. Such networks can use a commonly accessed data base (such as the CIS as proposed for TDD operation in the IEEE 802.16h), or can exchange co-channel interference resolution information in a peer-to-peer manner. How co-channel interference is minimized by the cognitive elements of a number of wireless networks re-using the same spectrum in the same geographic local is beyond the scope of this document, though an example is given at the end. What is proposed and discussed herein is an overview of the messaging that would be required by license-exempt cognitive radio to operate in an FDD environment.

1.1 Introduction to FDD with RF Reuse

The following diagram shows an example of radio frequency reuse with frequency division duplexing, where a FDD pair of frequecies is used 2 times per Base Station cell, and where 3 such cells are co-located. The FDD pairs are labeled A, B, C, and D. The downlink, from BS to all subscriber stations (SS), operates on a point-to-multipoint basis. The IEEE 802.16 wireless link operates with a central BS (1,2 & 3) and a sectorized antenna that is capable of handling multiple independent sectors simultaneously. Within a given radio frequency channel and antenna sector, all SSs receive the same transmission frames, or part thereof. The BS is the transmitter operating in this direction. Due to RF reuse in a same BS cell and adjacent cells, co-channel interference will likely occur in this scenario during installations of new SS links, because of propagation changes, or for example during or raining or snowy days (backscatter phenomena). Co-channel interference victims and sources are the BS and/or SS. Electromagnetic isolation and uplink/downlink power control can mitigate such interference, but never completely control it.



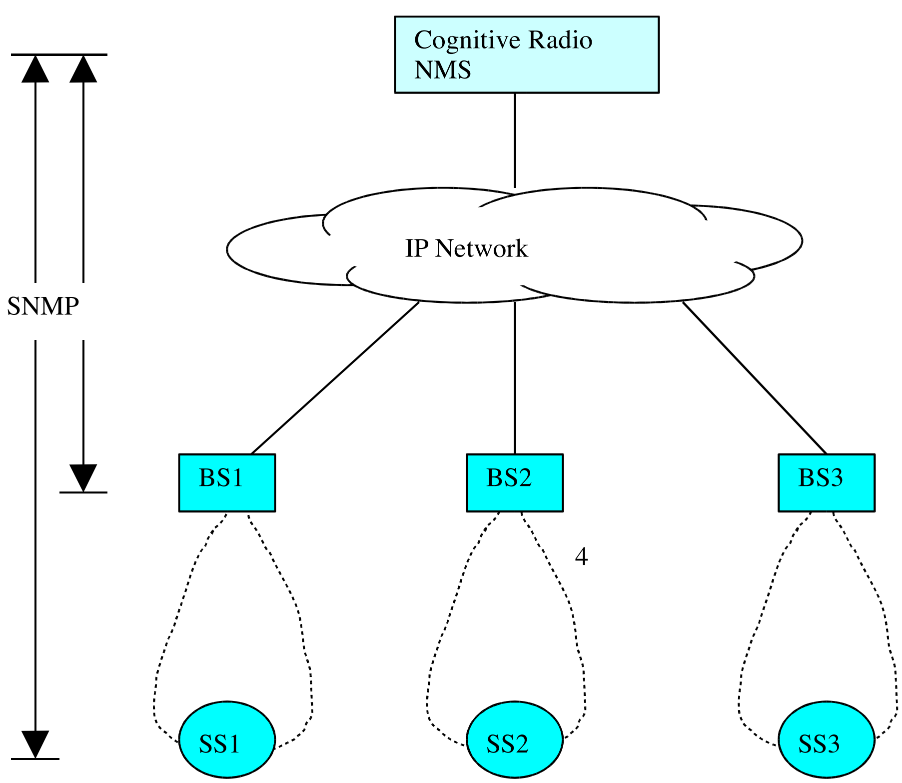
2. Co-channel interference detection and prevention

2.1 General Cognitive Radio Architecture

Co-channel interference that cannot be controlled by electromagnetic means must be identified and controlled at the packet level. This can be done by tagging all frames transmitted by the 802.16 radio and identifying such frames as interference when they appear at unintended destinations. Interference events are sensed by the radio terminals, be they subscriber or base stations, and information discerned from the interfering packet would be forwarded to a Cognitive Radio Network Management System (CR-NMS) that could be resident on a number of levels; such as within the base stations or at a central regional location. The CR-NMS would be able to reconfigure the EIRP, frequency band of operation, direction of antenna main lobes, direction of antenna nulls, etc. of the subscriber/base station terminals in a manner that mitigates the interference.

Shown below is an example of cognitive radio network management system (CR-NMS) for a network of 3 base station cells that could, for instance, form a network for a single service provider. Sensed co-channel interference could for example be packets from SS1 destined for BS1 that are detected at BS2 and /or BS3. Conversely, packets generated by BS1 and destined for SS1 may be received as interference at SS2 and SS3. Such interference is tagged with information such GPS coordinates, Base Station or Subscriber Station ID, EIRP info, antenna radiation characteristics of the emitter. This being provided the interfered-with terminal relays the interference incident (via an SNMP protocol) to the CR-NMS. At the CR-NMS analysis is undertaken concerning the interference incident and a decision can be made to limit interference from an offending terminal by lowering its EIRP, changing its channel, or directing it to steer an antenna null. If the interference is due to a terminal attached with a different, adjacent service provider, the CR-NMS has information that can be used in conjunction with the CIS (common identification server) to notify the adjacent service provider of the interference it is causing.

Tagged messaging can be an important interference control mechanism by preventing co-channel interference. Any new terminals entering a service area would be obliged to monitor there proposed license-exempt bandwidth prior to initiating service. The existence of tagged messaging would be a quick and succinct method of informing a newcomer on the spectrum occupancy and location of radio emitters, thereby aiding in the new terminal in the search for unoccupied spectrum.



The communication between BS and CR-NMS is based on standard SNMP protocol, as is the SS and CR-NMS communication. Cognitive radio MIBs need to be defined.

2.2 Co-Channel Interference Detection and Prevention

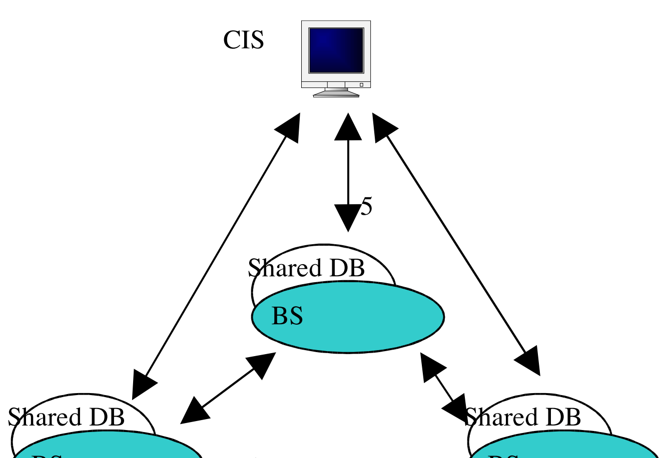
To detect the co-channel interference in the FDD IEEE 802.16h environment, two new MAC messages are defined: SS_MEM and SSURF. SS_MEM message is a downlink broadcast message from BS and it contains base station ID and antenna sector ID, amongst other RF information. This information will help receiving SS to determine which BS this message is received from. If it is not broadcast from the home base station (that it registered with), the SS concludes that co-channel interference is originating from another BS. In this case, SS will send a BS_CCID_IND trap message to Cognitive Radio Network Management System (CR-NMS) to indicate a co-channel interference event, with the identification of the source and victim. Upon receiving this SNMP trap message, CR-NMS will, based on its CR algorithm, take appropriate action to prevent this co-channel interference from happening again.

SSURF message is an uplink message sent by the SS to its home BS. If the base station ID of a received SSURF message is different from that of the receiving base station, co-channel interference will be identified as occurring from a SS uplink not associated with the correct base station. In this case, BS will send a SS_CCID_IND trap message to Cognitive Radio Network Management System (CR-NMS) to indicate co-channel interference source and victim. Upon receiving this SNMP trap message, CR-NMS will, based on its CR algorithm, take appropriate action to prevent further co-channel interference.

Cognitive radio management is a closed-loop control system; CR management decisions are usually made by cognitive radio algorithm based on co-channel interference feedback from the BS/SS under its management. Any message lost in this closed-loop system will be feedback again if the appropriate action is not taken. Therefore, SNMP/UDP as a transport mechanism can be adopted. Since every instance of co-channel interference will cause a SNMP trap message generated, CR-NMS will receive these traps even if a SNMP trap message lost because of the nature of UDP protocol.

2.3 Comparison between the FDD and Proposed TDD coexistence scheme of IEEE 802.16h

The current IEEE 802.16h TDD coexistence proposal is based on distributed radio resource management architecture as shown below.. It requires handshaking communications among base stations and between base station and a new entity called a CIS (common identification server). Its coexistence protocol specifies 30 messages so far to fulfill these handshaking communications. 20 of these messages are specified for communication among base stations, the other 10 messages are for communication between the base station and CIS server.



Current IEEE 802.16h System Architecture

It should be noted the CIS would be controlled by a regulatory jurisdiction responsible for spectrum policy surrounding the use of License Exempt bandwidth. That all regulatory jurisdictions worldwide may not want the responsibility for managing a CIS, or allowing one to exist, it is contingent on the part of a proposed coexistence standard to allow peer-to-peer resolution of co-channel interference without the use of a CIS, especially if the standard is to be used worldwide. The proposed messaging allows CR to use either the CIS or peer-to-peer approaches for interference regulation.

The following table lists some differences and commonalities between the current TDD IEEE 802.16h and the FDD CR-NMS proposal. The MAC messages that are proposed can be new; but their content suggests that within the IEEE 802.16 2004 complement of MAC messages and PDUs, it may be possible to identify existing MAC messages which can be used without the creation of new messages.

It is known that much of the information contained in the new MAC messages can be culled from the existing IEEE 802.16 2004 complement of information. However, the issue that is faced is one of the complexity in finding and quickly extracting such information so that it can be useful for interference control.

Feature	Current 802.16h TDD Proposal	FDD CR-NMS-proposal
Cognitive Radio Management	Possible	Yes
CCI control approach	Assignment of time-slots to coexisting TDD users, so that co-channel users occupy different slots of time	Universal identification tags that accompany all radio packet emissions.
Centralized RF database	Yes	Not imperative but useful
Distributed RF database	Yes, 10 messages specified for Registration, and DB synchronization	No, all detected interference contains necessary parameters to allow mitigation. CIS base useful for messaging between independent BS-BS exchanges.
Co-existence protocol for BS-BS	Yes, 20 messages specified for TDD sync, power control, and topology update.	No, CR that undertakes this and will be proprietary
SNMP requirement	Not clear, MIB mentioned in its working Doc	Yes, MIBs defined for CCI control
Power Spectrum Density	No	Yes, to detect interference below threshold of demodulators and non IEEE 802.16h sources.

New IEEE 802.16h MAC message	No	2 new MAC messages specified, but content of these messages suggests that existing messages may suffice.
Interference Identification	Base Station scans for interfering BS, and by use of BS data bases, frame number, sub-frame number, etc. will identify interfering BS	Extracted directly from a MAC PDU appended periodically to the uplink and downlink frames.
System Requirements for CCI control	Synchronized, co-channel networks transporting interference source information that can be universally demodulated/decoded.	Co-Channel networks transporting interference source information that can be universally demodulated/decoded.

Comparison of FDD and TDD Coexistence Messaging Requirements

3. Cognitive Radio Message Specification

There are 8 messages defined to meet the cognitive radio requirement for FDD IEEE 802.16h operation. Two new MAC messages are defined for use between the BS and SS. These messages are called "tags" since the tag the radio packet communication bursts which create co-channel interference. Other six messages are SNMP related information and traps, they are used to transfer radio frequency information to a centralized or decentralized radio database and its cognitive radio algorithms, which determine the appropriate actions to mitigate the co-channel interference. These messages are:

1. SS_MEM – a downlink tag broadcast message to all SSs in the same antenna sector.
2. SSURF – an uplink tag message sent by SS to its home base station.
3. BS_CCID_IND – a SNMP trap message sent by BS to indicate co-channel interference detected
4. BS_CCID_RSP – a SNMP "set" message to BS.
5. SS_CCID_IND - a SNMP trap message sent by SS to indicate co-channel interference detected
6. SS_CCID_RSP – a SNMP "set" message to SS.
7. PSD_REQ – a SNMP "set" message to start PSD sampling
8. PSD_RSP – a SNMP "get" message to get PSD data table.

3.1 SS_MEM – Downlink message

The subscriber station membership (SS_MEM) message can be a new (or modified) MAC message for IEEE 802.16h FDD. The BS broadcasts a SS_MEM message in each RF sector at a periodic intervals, inserted within the DL MAC PDU. It defines the radio emission characteristics of the downlink of the sector, and provides information on uplink FDD channels utilized by the sector and could include channel width information as well. The message is encoded in the following format:

BS_ID	Sector_ID	DL EIRP	Uplink RF	FrSeq#	BS IP address

Parameters:

1. BS_ID: The base station ID. This information will help SS to determine which BS this message is received from. If it is not received from the home base station (it registered with), then it is co-channel interference caused by another BS downlink. In this case, a BS_CCID_IND message shall be send to Cognitive Radio Network Management System (CR_NMS) to indicate co-channel interference source and victim. Upon receiving this message, CR_NMS will initiate a response, which

could access the CIS or be determined by the CR-NMS by itself, based on the SS_Mem contents.
2. Sector_ID: Identifies the Sector antenna broadcasting this SS_MEM message. This information will help SS to determine which BS sector this message is received from. This could contain the GPS location, height of sector antenna, beamwidth of sector and direction of sector antenna, etc.
3. DL EIRP: Down link EIRP of sector
4. Uplink RF: Uplink RF frequency channels used by this sector
5. FrSeq#: Frame sequence number
6. BS IP address: IP address of the base station that broadcasts this message.

3.2 SSURF – Uplink message

The subscriber station uplink radio frequency (SSURF) message shall be a modified (or new) MAC message for IEEE 802.16h. This message is periodically sent by SS as uplink tags, but could also contain interference and other event information experienced by the SS.

BS_ID	Sector_ID	FrSeq#	APL	EIRP	GeoPl	Ch_State

SSURF message fields are:
1. BS_ID: The base station ID to identify which base station this message is sent to. This information will help receiving BS to determine if received packet is CCI. If BS_ID it is different from the receiving base station ID, co-channel interference has occurred with another SS uplink. In this case, a SS_CCID_IND trap message shall be send to Cognitive Radio Network Management System (CR_NMS) to indicate co-channel interference source and victim. Upon receiving this message, CR_NMS will, initiate a CR response, which could access the CIS or be determined by the CR-NMS by itself. A response could be based on the SSURF contents.
2. Sector_ID: Identifies the destination sector antenna of this message. In essence, it is the same field as used in the SS_MEM message. Contains information, that if this packet is received as CCI, can to transported to a CR_NMS within the SS_CCID_IND trap message.
3. FrSeq#: Frame sequence number.
4. APL: Antenna parameter list giving information on antenna type (adaptive w/parameters; beam width, polarization, diversity, etc) of SS
5. EIRP: EIRP of transmitted SSURF
6. GeoPl: Geographical placement of SS, Range from associated BS, GPS coordinates, etc.)
7. Ch_State: mean fade duration, mean fade depth, variance of DL signal strength, Bit Error Rate mean, Bit Error Rate Variance, RSSI mean, RSSI variance, etc.

Upon reception of this message, BS will stamp the message based on the arrival time and translate the information into internal format for construction of a SS_CCID_IND trap message.

3.3 SS_CCID_IND

This is a SNMP trap message sent by a SS to CR_NMS when co-channel interference is detected at SS. This trap message shall contain the following minimum information to help determine the source and victim of co-channel interference:

BS_NUM: total number of base stations from which CCI interference is detected.
BS_ID: the base station IDs causing CCI
Sector_ID: the sector IDs of the base stations causing CCI
SS_ID: the SS that sent this trap.

Essentially, this message will contain a table of co-channel interference sources for this SS.

Base station ID	Sector ID
123456	2
234534	4
…	…

3.4 SS_CCID_RSP

This is a SNMP "set" message; it is to set the emission or reception qualities of the specified SS. Upon receiving co-channel interference notification, the cognitive radio algorithm in CR-NMS will determine an appropriate CCI mitigation decision and forward
This message to the victim SS.

SS_CCID_RSP can contain the following information for example:

SS_ID: the ID of subscriber station that causes/receives co-channel interference. It is the receiver of this message.
EIRP for the specified SS. This is a reduced/increased EIRP value for this SS based on cognitive radio algorithm.
Downlink/uplink frequency change.
Reregistration request to a new BS
Specification of allowable uplink timing slots.
Adaptive antenna configuration parameters for reception/transmission.

3.5 BS_CCID_IND

This is a SNMP trap message sent by a BS to CR_NMS when co-channel interference is detected at BS. This trap message shall contain the following information to help determine the source and victim of co-channel interference:

SS_NUM: total number of subscriber stations that interference events were noted.
SS_ID: the subscriber stations ID that causes the co-channel interference
Sector_ID: the sector ID of the subscriber stations that cause interference
Source basestation ID: the BS that sent this trap message.
Source sector_ID: the antenna sector that detects the co-channel interference.

Essentially, this message will contain a table of co-channel interference sources for this BS.

3.6 BS_CCID_RSP

This is a SNMP "set" message; it is to set the configuration of the BS. Upon receiving co-channel interference notification, the cognitive radio algorithm in CR-NMS will use this message to set the emission or reception qualities of the specified BS. It shall have the following information:

BS_ID: Base station ID of Base Station receiving/causing interference. It is the receiver of this message.
EIRP for the specified BS
Downlink/Uplink frequency change.
Adaptive antenna configuration parameters for reception/transmission.

3.7 PSD_REQ

All co-channel interference that is created cannot necessarily be demodulated or decoded correctly, 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. In this event 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. "Snapshots" of spectrum space are useful to

CR systems, especially when new base stations or terminals are installed and are searching for unoccupied spectrum.

This is a SNMP “set” message, it is requests a BS or SS to sample PSD (power spectrum density) data for next “get” message. Since sampling PSD data will take some time, depending on environment, nature of bursty users, the following “get” message shall wait long enough for BS/SS to complete the PSD data sampling.

There shall be only one SNMP scalar MIB object defined for this operation.

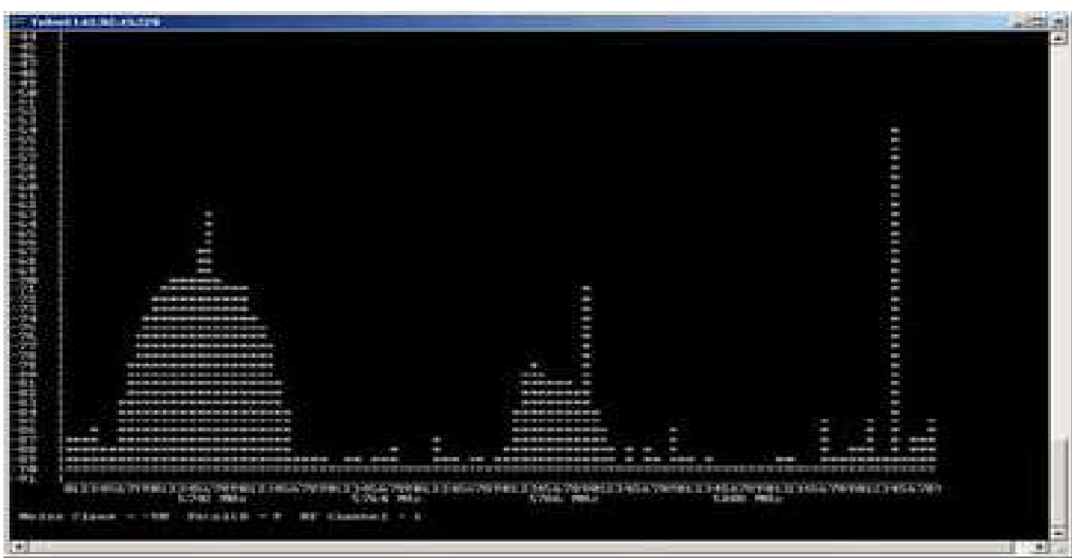
3.8 PSD_RSP

This is a SNMP “get” response message, SNMP MIB objects shall be defined accordingly; it shall contain the following values for a complete PSD:

1. Antenna Parameter List containing attributes of antenna undertaking PSD
2. X-min, the lower bound of channel frequency (in kilohertz)
3. X-max, the upper bound of channel frequency (in kilohertz)
4. Resolution bandwidth
5. Power spectrum density measurement

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 STRUF_REP message (i.e. $(X_{max} \quad X_{min})/(resolutionBandwidth) \quad 1$).
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.

Here is an example of PSD display:



4. CR response example

A base station and a subscriber terminal have an established link that sees no co-channel interference. A second base station not associated with the first enters the network. It creates co-channel interference detected by the subscriber. The subscriber terminal detects the SS_MEM message and forwards a SS_CCID_IND message to its CR_NMS (which could be resident in its Base Station). The CR_NMS system reads the IP address of the interfering base station and forwards the SS_CCID_IND message, which may be modified, to the interfering base stations CR_NMS system (resident at the IP address of the interfering BS).
The interfering Base Station's CR-NMS on receiving the SS_CCID_IND and reading the Sector_ID where the interference occurred can make a decision, for instance, changing the downlink frequency that it sends to the given Sector_ID or steering a null in the direction of the Sector_ID. It can also make no decision until numerous other SS_CCID_IND message are received indicating the creation of a much higher level of interference.

Another response on behalf of the Interfered-with Base Station and its CR_NMS could be to send a SS_CCID_RSP to the interfered with Subscriber Station telling it to use its adaptive antenna to introduce a null in the direction of the interfering BS.

5. Conclusion

It is proposed that by tagging IEEE 802.16h uplink and downlink frames with messages giving details on the emission characteristics of the radios in a LE network, enough information is transported to allow cognitive radio algorithms to operate and mitigate CCI, thereby achieving high levels of co-existence.

It is proposed that a more detailed description be provided for such operation once FDD operation in the IEEE 802.16h is recognized.