Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Examination of proposed interference resolution techniques and messaging for IEEE 802.16h & additions to working document 802.16h-05_022**
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Re:	Call for Contribution, “IEEE 802.16’s License-Exempt (LE) Task Group”, 2005-10-17 Item 4.
Abstract	This document contains additions to the draft IEEE802.16h working document and raises some questions about the efficiency of currently proposed approaches to interference resolution as outlined in the subject working draft document. The sections and paragraphs given below refer to those of the subject working draft document IEEE802.16h-05/022. All direct additions to the working document are given in italic font and included below
Purpose	This document contains additions to the draft IEEE802.16h working document and raises some questions about the efficiency of currently proposed approaches to interference resolution as outlined in the subject working draft document. It is to be discussed in IEEE 802.16 meeting, session #40.
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Examination of proposed interference resolution techniques and messaging for IEEE 802.16h & additions to working document 802.16h-05_022

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Overview

This document contains additions to the draft IEEE802.16h working document and raises some questions about the efficency of currently proposed approaches to interference resolution as outlined in the subject working draft document. The sections and paragraphs given below refer to those of the subject working draft document IEEE802.16h-05/022. All direct additions to the working document are given in italic font and included below.

4 Abbreviations and acronyms
(proposed additions)

SSURF - Subscriber Station Uplink Radio Frequency
CR - Cognitive Radio
NOC - Network operation center
CR_NOC –Cognitive Radio Network Operations Centre.
PSD - Power Spectrum Density
UTC –Universal Coordinated Time
CNTI- Cognitive Network Time Interval
PLE- Path Loss Exponent

15.2.1.1 General Principles.

The General Principles section of the current Draft Standard are important in that they must lay out the basic operating features of the proposed IEEE 802.16H Standard. Currently the General Principles do not completely reflect the issu es that are faced in operation of license-exempt technology worldwide. The licensed exempt bands are large in extent, covering spectrum that exists at 2.4 GHz, 3.65 and 5.2-5.8 GHz, depending on the jurisdiction. How this spectrum is used, what spectrum i s used, and what safeguards are provided to ensure its viability, especially to primary users, varies with each country and regulatory jurisdiction. The General Principles should reflect this variability.

It is recommended that as a General Principle, IEEE 802.16H radio systems implement avoidance of co-channel interference as the first step toward coexistence. Even though it may be an obvious step, the current documentation does not reflect such procedures.

One issue that has not been addressed is the sharing of the spectrum with other networks which may be cognitive and strive for coexistence, but are fundamentally different from IEEE 802.16. (for example Ultra Wide Band systems). It is important that the General Principles recognize this and strive to accommodate such other systems. A step forward to doing this could be the establishment of common time base and synchronization standard that could support timing for inter-CR network messaging. This is described in more detail below.

To further ensure coexistence with LE CR networks that are not compliant to the IEEE 802.16h standard, it should be made apparent that as a General Principle, the IEEE 802.16h standard will provide an opportunity for systems to communicate at both the RF PHY and IP layer with IEEE 802.16h systems. Setting such a requirement for the first time within IEEE 802.16h would set a precedent for other LE CR systems.

Coexistence with co-channel system having a higher priority access has not been identified within the General Principles of the IEEE 802.16h. Yet this is an important technical requirement, often sited in WRC 2003 and dealt with ITU-RM 1652. Coexistence with Radar users is important and methodologies to achieve this must be specifically identified within IEEE 802.16h.

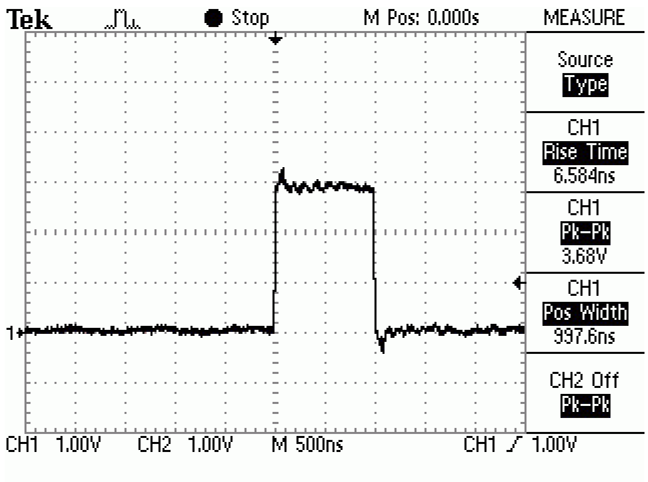
(Proposed Addition) 15.2.1.1 General Principles

The following sections are for inclusion in Section 15.2.1.1

- *All Base Stations and their networks will as a first step seek the avoidance of co-channel utilization of spectru, and will be equipped with a spectrum detection and monitoring capability which will allow this.*
- *All base stations are synchronized to a GPS clock which will distribute a universal timing indication to all base stations and their networks.*
- *All base stations and their networks, operating in the LE bands, will provide the opportunity to other non-IEEE 802.16h systems to communicate their coexistence requests to the IEEE 802.16h networks.*
- *The IEEE 802.16h will recognize the use of radar and systems having higher priority to LE spectrum and will have mandatory signaling that will support the recommendations of ITU-RM 1652.*

15.7.2.1 GPS Timing and Base Station Synchronization

It is proposed that every base station be equipped with a GPS receiver capable of receiving a UTC synchronized 1 pps timing signal. The accuracy of the clock pulses derived from using GPS are accurate to +/- 50 usec (equipment dependent) and the pulses that are derived typically have rise times within +/- 2.5 nsec. Fig 1 shows a typical GPS UTC 1 sec pulse and its duration (Trimble Inc. Palisade output). It is proposed that the 1 sec duration be used throughout the IEEE 802.16H networks as the Cognitive Network Time Interval (CNTI). The rising edge of the 1 pps GPS synchronization pulse will be considered as the start of the CNTI.



The availability of a globally distributed clock will provide a common temporal unit that can be used in negotiating access times to common spectrum in a locale shared by a community of ad-hoc users. Different cognitive networks, having different architectures and messaging signals, would conceivably conform to the use of a common 1 sec interval for synchronization of their networks as well.

The one second unit is considered ideal because it is distributed by the GPS as such and the length of the unit is seemingly appropriate. IEEE 802.16H networks typically have frames in the order of several to tens of milliseconds, which is of a granularity that co nceivably allow several to several tens of networks to negotiate coexistence subintervals within the 1 second span. Additionally, for IP networks, the 1 second interval is more than adequate to accommodate inter -router TCP/IP latency, especially over networks that are likely close to each other, as ad-hoc LE networks shall be.

(**Proposed Additions) 15.7.2.1 Base Station Synchronization**

15.7.2.1 BS Synchronization
15.7.2.1.1 GPS Synchronization of the IEEE 802.16H MAC

All base stations forming a commun ity of users sharing common radio spectrum will use a common clock to synchronize their MAC frames. The common clock will be synchronized to the GPS Navigation System. Every BS upon activation, will as a first step ensure the derivation of the common GPS system clock.

15.7.2.1.1.1 Cognitive Network Time Interval

All synchronized IEEE 802.16H base stations will derive the 1 pps clock broadcast by the GPS system and use the UTC time standard that is also distributed by this system. The 1 sec duration is called the Cognitive Network Time Interval (CNTI). The rising edge of the 1 pps GPS synchronization pulse will be considered as the start of the CNTI.

15.7.2.1.1.2 Granularity of the CNTI

The CNTI will be comprised of 1000 1 Millisecond slots that will be used by both TDD and FDD networks to negotiate times and durations of co-channel occupancy. Negotiation for access time to common spectrum will be specified in terms of the 1 millisecond units. Occupancy times will be specified in terms of time from the beginning of the CNTI and in terms of negotiated number of 1 millisecond intervals.

15.7.2.1.1.3 UTC Standard Time

IEEE 802.16h base stations, in the process of negotiating occupancy times, will use the UTC time standard distributed by the GPS system for coordinating and identifying specific CNTI intervals. Coexisting networks will negotiate occupancy of future CNTI period by specifying the specific period in terms of UTC parameters.

15. 2.1.1.3 Coexistence Time Slot

The current structure and description of the CTS makes it impossible for other non-IEEE 802.16H systems to indicate their presence. Furthermore, the slot is rarely used, since it is only for network discovery and neighbor broadcast applications.

The complexity of specifying CTS timing, as detailed currently within Sec. 15.2.1.1.3, can be removed if the use of GPS timing and UTC time stamping is implemented, as suggested below. As a general recommendation, it is put forward that the CTS time slot be differently specified.

Since all IEEE 802.16H networks will by synchronized and use UTC time stamp retrieval, which can be implemented in non-IEEE 802.16H networks as well, it is recommended that:

- The CTS be inserted only every 30 seconds, at the UTC minute and half minute.
- That the CTS be inserted at the end of the CNTI for a fixed duration of 10 milliseconds.
- That the signaling used within the CTS be universally demodulate-able, allowing non OFDM LE CR systems to discern its presence and abstract the intended IP information from it.

Potential Problems with the Coexistence Time Slot Approach to resolve CCI

There may be a fundamental flaw in the use of the CTS slot to resolve CCI. It is noted in 15.2.1.1.3 that the CTS is used for discovery purposes by newly entering networks (see also Sec 15.5.1.5 of IEEE 802.16h-05/022). It is assumed that through the discovery process, new and potentially interfering networks can be identified. The rational for this is simple: a new network (initializing) BS broadcasts its IP address over the CTS and all foreign SS receiving the broadcast IP message thus identify themselves as potential CCI victims of the new network. The victim SS can then initiate a process of CCI identification and resolution (the network entry process).

While the CTS discovery process will work, it is propagation environment dependent. Here are a few scenarios that can be supported by literature, where the limitations of the approach become evident:

- Co-channel cells or highly reflective objects (such as large buildings with aluminized windows) can be minimally isolated by vegetation, or the vegetation may be covered by water (resulting in a significantly higher PLE). During the CTS discovery process, such obstructed sources of CCI may not be detectable. After the new entrant is accepted with in one community, the isolation created by the vegetation changes (these changes can be significant on a seasonal basis), resulting in CCI to undiscovered networks. Also, weather such as snow can cause powerful reflections of 5 GHz signals, resulting in highly transitory CCI phenomena that will confound the CTS based co-existence approach because of inherent slowness to respond to such phenomena.
- Discovery is dependent on the SS receiving the CTS signaling and informing their host BS of the interference. New additions of SS results in a new network topology that now sustains interference from previously co-existing networks.
- The discovery process using CTS depends on the successful demodulation and detection of the CTS data. The level of the CTS signals may be continually below the demodulation threshold of the interfered-with networks' SS. The inability to resolve this can result in a raised interference noise floor to the victim network and result in sporadic instance of CCI to it because it was not able to identify itself as a potential victim during the initializing Base Station's CTS procedure.
- The CTS discovery scheme when used with TDD systems identifies symmetric interference: ie, the detection of interference at a SS means that the SS will interfere with the BS as well, assuming propagation path symmetry. This is not the case for FDD where the uplink and downlink paths are different. CTS interference detection on the downlink (BS to SS) will not necessarily happen in the uplink (SS to BS); because of the different propagation paths due to different channel frequencies used by FDD.

Potential Solutions

The difficulties addressed above can be in part resolved by having initializing BS and SS undertake spectrum monitoring prior to any network entry. Refer to 15.6.1.35 for details on this. Frame by frame monitoring of both uplink and downlink messages can provide useful and almost immediate CCI information. Refer to sections 15.6.8.2.3 and 15.6.8.2.2 of current working document for details.

Another potential solution, though not as thorough in its ability to detect CCI, is to use the CTS continually as a BS to SS signaling channel. If the UTC time standard is adopted, coexisting BS can broadcast the CTS channel every second in a round-robin manner. Empty slots can be left (10 second intervals for example) to allow entry of new networks.

Proposed Changes

To be discussed during November 14-17 meetings.

15.2.1.3 Community Entry of new BS

This section describes the entry process of a new network into a community of established networks on a non-interfering basis. As detailed in the discussion above (Sec 15.2.1.1.3), the current approach relying on CTS cannot guarantee an interference-free community of networks. The reliance on a centralized database to contain global information about the community is also questioned and addressed in the comments given below (15.2.2.1). As an extension to these comments and the proposed changes to the current working document IEEE802.16h-05/022 that have been addressed in IEEE S802.16h-05/038 and IEEE C802.16h-05/039, an addition is proposed for Section 15.2.1.3 which is outlined below.

(Proposed Additions) 15.2.1.3. Community Entry of New BS

1. It is assumed the there is a commonly available database to all LE users, and that this database is IP addressable by a base station and its NOC or CR_NOC. This database shall contain the following information:

- *IP address of base station or the NOC controlling it*
- *GPS location of the base station.*

2. It will be assumed that all LE base stations compliant to IEEE802.16h are synchronized to a GPS 1pps clock, and can derive UTC time stamps from the downlink GPS signal.

3. All base stations compliant to the IEEE802.16h will have a commonly agreed method of weighting network access based on negotiable factors such as incumbency, throughput, operational efficiency, coverage area, EIRP, and other factors that support the requirements for a networ's use of the LE bands. These factors will be used by the Cognitive Radio processors within the base stations to negotiate spectrum access.

4. All base station and subscriber station terminals will have the capability to monitor LE spectrum and keep a record of the PSDs that are determined.

5. All base stations compliant to the IEEE802.16h will have a data base outlining the radio emission characteristics of the network controlled by that base station and its NOC.

The network entry process is as detailed in Figure 1.

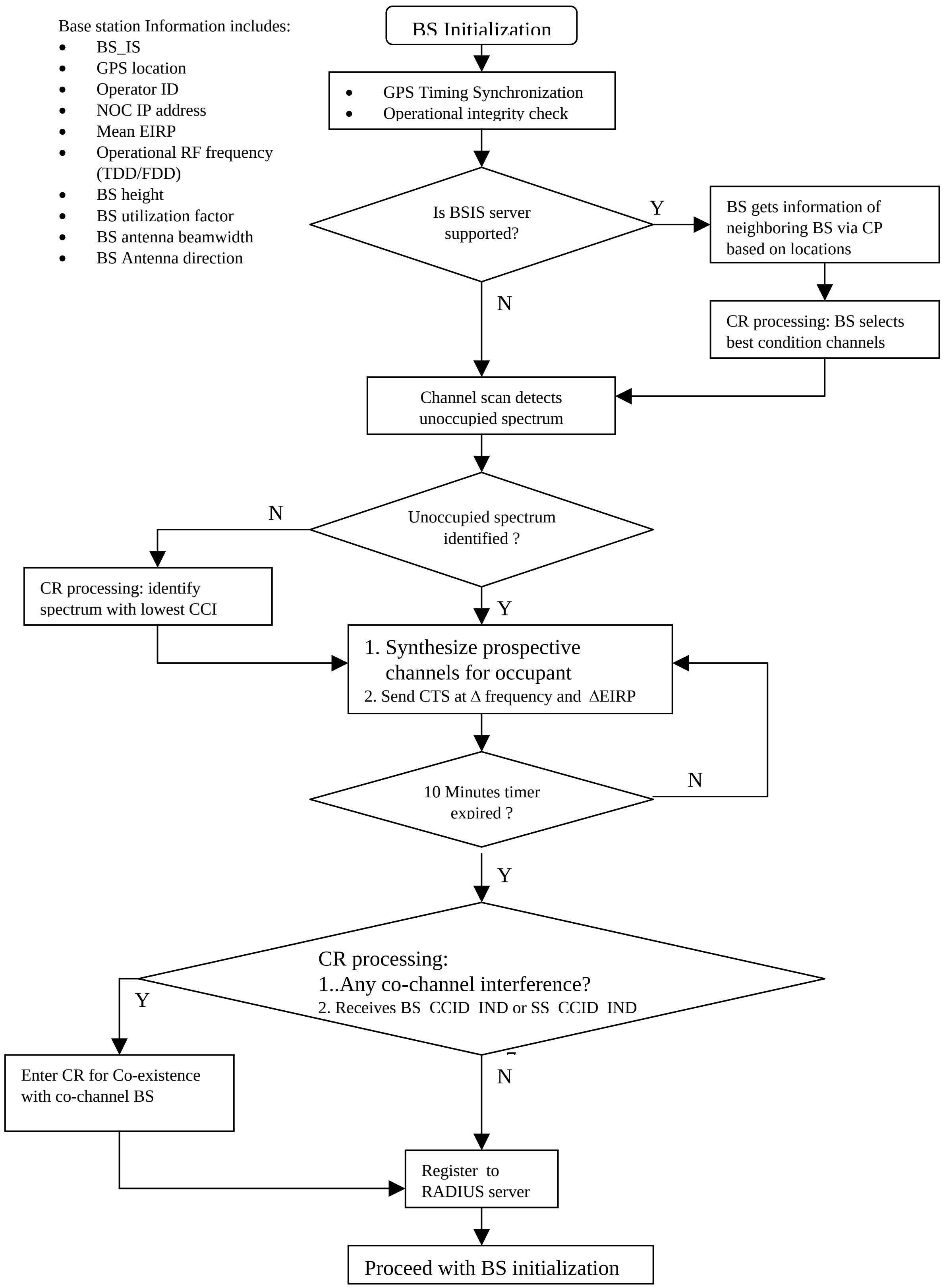

Base station Information includes:
• BS_IS
• GPS location
• Operator ID
• NOC IP address
• Mean EIRP
• Operational RF frequency (TDD/FDD)
• BS height
• BS utilization factor
• BS antenna beamwidth
• BS Antenna direction
BS Initialization
• GPS Timing Synchronization
• Operational integrity check
Is BSIS server supported?
Y
N
BS gets information of neighboring BS via CP based on locations
CR processing: BS selects best condition channels
Channel scan detects unoccupied spectrum
Unoccupied spectrum identified ?
N
Y
CR processing: identify spectrum with lowest CCI
1. Synthesize prospective channels for occupant
2. Send CTS at Δ frequency and ΔEIRP
10 Minutes timer expired ?
N
Y
CR processing:
1..Any co-channel interference?
2. Receives BS_CCID_IND or SS_CCID_IND
Y
N
Enter CR for Co-existence with co-channel BS
Register to RADIUS server
Proceed with BS initialization

Figure 1 Discovery Process

Network Entry Process by an Initializing BS.

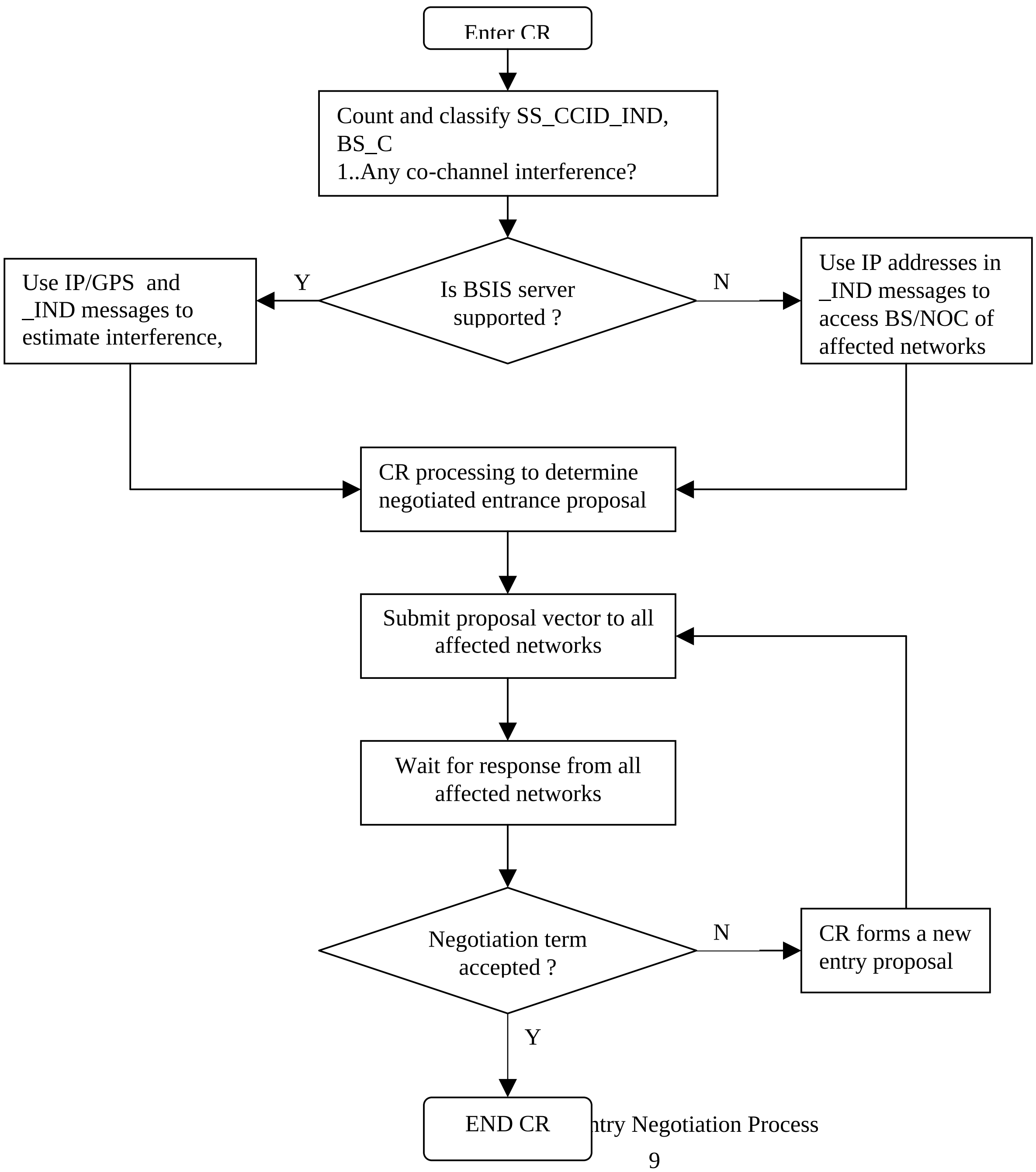
A newly entering BS, prior to establishing a network will undertake the following entry steps as shown in Figure 1.

- *On initialization, the Base Station will derive a GPS 1pps timing reference and the UTC time stamp.*
- *The BS will determine its GPS location.*
- *The BS will then check to see if it has the IP address of a remote database that will allow network discovery of other BS.*
- *IF an BSIS server or IP data base address exists, the BS will determine the GPS locations and IP addresses of all potentially interfered with stations. If no BSIS or database IP address exists, potentially interfered-with station are not known, but still can be present.*
- *The BS then undertakes a spectrum scanning process, searching over its intended coverage for zones of no occupancy. If occupancy exists, it will be graded by the CR processor associated with the base station. If all spectrum is empty, proceed to sending of CTS.*
- *CTS messages are sent at every opportunity for 10 minutes*
- *Responses in the form of BS_CCID_IND and SS_CCID_IND messages are received at the initializing BS and used for the coexistence protocol. If no responses are provided the initializing BS proceeds with registration of its IP address and GPS location with the "Radius" server or equivalent.*

In the event that co-channel interference from proximate BSs is identified, the initializing BS will be required to use a coexistence protocol (TBD) and negotiate entrance into the existing community of networks. Negotiation between the BS and their CR_NOC can be undertaken by the exchange of "negotiation vectors" which quantify systemic parameters such as incumbency, coverage area, network efficiency, etc.

The CR negotiation protocol is shown in Figure 2. The salient features of the protocol are:

- *After the CTS discovery the _IND messages are counted and correlated with IP data/GPS location data of proximate BS. The Cognitive Processor at the initializing BS or the BS_NOC categorizes interference instances, conducts analysis for hidden nodes (ie, for networks which are proximate, but gave no responses) etc.*
- *The initializing CTS, having identified the community or proximate networks that it seeks coexistence with, communicates with the base stations (or their CR_NOCs) and initiates a process of information exchange in which the contacted networks provide the initializing network with details on their operation. This process will likely require some form of private key exchange to transport sensitive information.*
- *Information received by the initializing BS (BS_NOC) is then used to create a "negotiation vector", which is really a submission, or series of submissions to the base stations with which coexistence is sought. The transaction occurs at the TCP/IP layers. The operating BS examine the effects of the "negotiation vector"*
- *Operating BS either accept the proposal or reject it. The process is undertaken until a coexistence scheme can be rationalized whereby space, time, and coverage area are negotiated for use in manner favorable to all networks. Once agreement is reached, operating and initializing BS configure their operation for the new ad-hoc topology and community.*



ntry Negotiation Process

Ad-Hoc Network Coexistence

The community of coexisting networks maintains coexistence and identifies sporadic interference caused by propagation changes by continually monitoring the uplink and downlink frame headers. Foreign packets will result in the generation of BS_CCID_IND and SS_CCID_IND messages that are used by the CR_NOC of affected base stations to initiate communications with the interfering stations, which may or may not be part of a negotiated, coexisting community.

Alternatively, the CTS message frame can be used in a round-robin manner by the community of network base stations, to broadcast IP identities, that can be identified as foreign interference. This process is mentioned in Section 15.5.1.5 of the current IEEE802.16h-05/022.

The coexistence process is thus continual and requires constant monitoring by the BS_NOC, which maintain TCP/IP communications between themselves.

15.2.2.1 Architecture

The current architecture is structured around the existence of a Radius Serve and a Coexistence Identification Server (CIS). Whether such a centralized structure will be supported in the many and varied jurisdictions is debatable. No indication is given as to who would oversee the operation and maintenance of these servers. At question, also, is whether Base Station operators will allow the perusal of their bases stations' databases by other competing and unidentified (to them) users. License-Exempt band use does not presently compel operators to reveal or make such information available. Entry of data into such a database may only be undertaken at the discretion of the operators, unless regulations force otherwise.

This being said, there is reason to have some central location to which base station NOCs can refer to get information about their local environment. The database could contain all LE users, and not only those compliant to the IEEE 802.16h standard. The process of network discovery is made more certain by having such data available to newly entrant networks. To achieve this requires only the minimum amount of information. For example, the association of static IP addresses (corresponding to the IP address of the NOC of the base station) and the GPS location of the base station would be sufficient to begin the network discovery process by an initializing BS.

A central data base containing minimal information may prove to be extremely useful for another issue that all LE system working in the 5 GHz bands will need to resolve: Dynamic Frequency Selection (DFS). DFS, as discussed in regulatory documents such as the ITU-RM 1652 and ETSI EN301 893, may be achievable and/or be enhanced by use of a common database having IP/GPS associations. Some of the radar signals which BS and SS need to detect are of such complexity that the simplest way to deal with them may be to use a systemic approach for detection and DFS information distribution.

Proposed Changes

It is proposed that the concept of the Coexistence Identification Server, Radius Server, and Regional Data base be re-examined in view of the fact that it may not be supportable in many countries and jurisdictions, and that there is no compelling regulatory requirement for such an architecture identified at this time.

It is proposed that a much simpler centralized record keeping framework be discussed, which would still support the coexistence objectives of the current architecture proposal outlined in Section 15.2.2.1 of IEEE802.16h-05/022.

15.7.2.2 Shared Radio Resources Management

Ultimately, altruistic cognitive radio networks will negotiate the equitable use of a common coverage area, frequency plan, and timing regime amongst themselves. A newly entering network into a community of established networks will have to go through a process of network discovery to determine the extent of its coverage, monitor spectrum, and in the event that spectrum needs to be shared, the new network will have to negotiate its entrance into the community. This implies sharing of common radio resources and their management.

There are a number of factors which should be considered in the process of spectrum sharing, some of which are outlined below.

(1) First come/ First claim: It can be argued that the original users of the spectrum should have some priority to it. The arguments can be based on the fact that the users are established and are effectively using spectrum and that it may be unprincipled to disrupt legitimate and established users. The arguments against this are that spectrum may be claimed by greedy users that have no capacity and are laying claim to spectrum in anticipation of future needs. Another argument is that initial users may be using spectrum ineffectively resulting in a larger community of users being penalized for the inefficiencies of others. It also may be argued that currently established users have a higher priority to the spectrum than newly arriving users… . but that this claim should disappear once the higher priority claim ceases operation. As a consequence there is also the issue as to how long a claim should last.

(2) Coverage area: A user with a broad beamwidth in azimuth and large coverage will uses spectrum less efficiently than a narrow beam width user, when both users have the same EIRP. It may be useful to use a metric (such as bits per sec per square kilometer) to prioritize the data transport efficiency of wireless networks. It may be argued that networks with higher delivery efficiencies need more protection, or should be preferential to less efficient networks.

(3) Throughput, QOS, and User Population: It may be argued that networks having larger user populations and real time traffic be granted more access both in time and spectrum. It could, for example, be unwarranted to give two networks of equal extent the same access rights to spectrum given that one network supports significantly more users than the other.

(Proposed Additions) 15.7.2.2 Shared Radio Resource Management

15.7.2.2 Shared Radio Resource Management

15.7.2.2.1 Legitimate Request for Bandwidth and Transmission Time

An IEEE 802.16H network that is a member of a community of networks granted access to shared spectrum resources only if it forms an actual network comprised of at least one base station and one subscriber station.

15.7.2.2.2 Coverage Area

An IEEE 802.16h network that is a member of community of networks will be required to provide an indication of the area coverage area that it occupies.

15.7.2.2.3 Throughput, QOS, and User Utilization

An IEEE 802.16h network that is a member of a community of networks will be required to provided an indication of the number of subscriber stations it is supporting and the average utilization of the spectrum that it has been granted access to.

15.2.2.3.1 Same PHY Profile

The current IEEE802.16 05/022 document alludes to the possibility of there being multiple PHY profiles for use in the LE bands. While the IEEE802.16 -2004 standard allows this , it also outlines a number or profiles and channel plans (Sec 12.2.3.2 of IEEE 802.16-2004) that support fixed profiles.

It is proposed that a minimum number of fixed profiles be standardized within the IEEE802.16h. Such standardization would support the production of commodity radio devices, hopefully providing the same impetus to industry as done with the IEEE 802.11 standards. Fixing the profiles would result is result in less stringent constraints on IEEE 802.16h design. A standard bandwidth would also ease the problem of network discovery and ease the signaling requirements.

It is recommended that a minimum number of fixed profiles be identified and discussed.
A suggested profile that could be considered for 5 GHz LE operation could be:

profM3_pmp,profP3_10,profC3_23,TDD/FDD,profR13

- WirelessMAN-OFDM Basic packet PMP MAC profile
- 10 MHz channel spacing

- 23 dBm EIRP and higher
- TDD or FDD
- 5.725- 5.850 Ghz LE band operation.