October 18, 2007

Julius Knapp, Chief
Office of Engineering and Technology
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: Written *Ex Parte* Presentation
ET Docket No. 04-186

Dear Mr. Knapp:

Motorola is a strong supporter of the FCC's proposals to make available spectrum allocated for television broadcast service for low power devices. It is imperative, however, that such ancillary use of the TV "white space" (TVWS) spectrum fully protect broadcast licensees and other incumbent services so that service quality is not materially diminished. Motorola's research and experimentation supports the premise that with appropriate restrictions, cognitive radio techniques can be successfully utilized to allow low power devices to utilize TVWS without causing harmful interference.

Attached is a whitepaper that details Motorola's conclusions and recommendations, based on its independent research, on how to effectively allow low power devices to use TVWS spectrum to provide new and innovative services. In the whitepaper, Motorola provides a technical and regulatory framework for use of the TVWS by fixed, mobile and portable devices while providing sufficient protection to authorized users of the TVWS bands.

As fully described in the attached, the whitepaper recommends the establishment of two classes of unlicensed devices within the TVWS; the first class would include relatively high powered devices (up to 36 dBm EIRP) and the second class would include lower powered consumer devices (up to 10 dBm EIRP), with technical and operational rules for each class that are appropriate for their likely use and interference potential. This multi-tiered approach allows the type of high power devices that are necessary when deploying broadband to rural areas, commercial, enterprise or other services covering large geographic areas, while also facilitating use of lower powered devices that will satisfy the need for limited range consumer devices typically deployed in homes and requiring much more limited coverage.

While regulatory requirements for all devices must be based on the need to protect authorized users, Motorola believes that the requirements for the two classes of devices should be different based on the potential of the devices to cause inference, and the likely uses for each class of device. To ensure that other users of the bands are not adversely impacted, the high power device requirements should include a multi-tiered approach to protection incorporating:

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- Geo-location Database - The device must have a means to determine its location and provide protection based on the use of an incumbent database that is maintained by an FCC-approved third party. The structure of the incumbent database could be very similar to the FCC's CDBS (TV Database Query) system. Use of a third party database provider will facilitate adjustments to the database based on feedback from users or licensees, and will facilitate entering protection information for short-term use, such as wireless microphones during large sporting events or other performances.
- Sensing – The device must include a means for sensing. While primary protection would be provided through use of the geo-location database, sensing will provide a secondary level of protection as well as facilitating sharing among white space devices.
- Detection of beacon – The device must support detection of the type of beacon being defined by IEEE 802.22.1. Support for detecting the beacon will allow higher priority users to control white space devices in a limited area. This will facilitate protection of devices such as wireless microphones and could enable priority among white space devices if the Commission determines that such tiered use is appropriate.

Combining these three mechanisms for protection provides highly reliable protection of higher priority users and services (including licensed services). It also ensures that a constant means of communicating with and controlling deployed white space devices exists, thereby facilitating adjustments to protection requirements as they develop and changes to the regulatory environment are desirable or necessary. Given the high reliability of this multi-tiered protection scheme, Motorola does not believe that high powered devices should be limited to fixed devices. Rather, fixed, mobile, portable, and "tethered" portable devices should all be permitted provided they meet the above criteria. Motorola also recommends that users of high-powered white space devices register the location and use of their device with the Commission. This will further facilitate control of deployed devices should a problem arise.

Motorola recommends that the operating and access requirements for lower power consumer device requirements include:

- Sensing – Devices would be required to use sensing to provide protection of incumbent users. While these devices would be limited to a maximum of 10 dBm transmit power in order to reduce the potential for interference, including by direct pickup by in-home cable equipment, the actual transmit power should vary depending on the sensitivity of the device's incumbent sensing receiver. Devices with less sensitive incumbent detection would be required to operate at reduced transmit power to ensure protection with a high degree of certainty.
- Detection of beacon – The device must support detection of the type of beacon being defined in by IEEE 802.22.1. As with higher power devices, support for detecting the beacon will allow higher priority users to control white space devices in a limited area facilitating protection of devices such as wireless microphones and providing a greater level of control over deployed devices than sensing alone.

- These devices should not allowed to operate on channels 14-20 to provide protection for land mobile systems used by public safety and enterprise operations due to difficulty of sensing non-broadcast signals in a mobile environment.

Motorola believes that fixed, portable and mobile devices should be permitted under this classification.

The multi-tiered protection framework provides numerous benefits:

- High reliability for incumbent protection.
- Potential to modify protection requirements through the database.
- Potential to add specific operations/scenarios that need protection, for instance a large event where a large number of wireless microphones may be used, or a cable head end location that is using off-the-air reception to obtain broadcast signals for retransmission.
- Ensures that deployed devices can be controlled and updated, providing a more reliable radio environment.
- Supporting the beacon provides the potential to protect areas and devices as needed in real-time, including wireless microphones. It also offers the potential for prioritizing use among TV White Space users if that is desirable.

Reliable protection of higher priority users along with provisions that provide reasonable access to open spectrum are the cornerstones for successfully allowing use of TV White space. Motorola recommends the multi-level approach described in the attached whitepaper which provides reliable mechanisms for protecting incumbents and offers new opportunities for broadband services. The same approach can be successfully applied to fixed, mobile and portable operations in a variety of configurations without an undue cost or technical impact. Motorola urges the Commission to adopt rules based on this multi-level approach.

Sincerely,

/s/ Steve B. Sharkey

Steve B. Sharkey, Senior Director
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Motorola Whitepaper:

Recommendations on Cognitive Radio (CR) Operations in TV White Spaces (TVWS)

Authors: Dave Gurney, Steve Kuffner, Greg Buchwald, Randy Ekl

1 Introduction 2
2 Geo-location Database-Enabled CR Device Comments 2
3 Sensing-only CR Device Comments 11
4 CR Device Transmit Masks 23
5 Disabling Beacon Approaches 29
6 Other Issues 34
7 Conclusions 37
8 Abbreviations 39
Appendix A – CR System Propagation Models 41
Appendix B – TVWS Device Spectral Masks 43

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1 Introduction

Motorola is a strong supporter of the Federal Communications Commission's ("Commission") efforts to make available spectrum allocated for television broadcast service for low power devices. It is imperative, however, that such ancillary use of the TV "white space" (TVWS) spectrum fully protect broadcast licensees and other incumbent services so that service quality is not materially diminished. There are a variety of techniques available to protect incumbent services. These include the use of geo-location databases, disabling beacons, and spectral sensing techniques. These approaches can be combined to provide multiple levels of protection. A combination of the above techniques offers the highest level of incumbent protection, while also allowing multiple levels of control over fielded TVWS devices (regulatory and otherwise).

Cognitive Radio (CR) device operation within the TVWS is required to meet the variety of sensing, geo-location, transmit power level, and frequency agile requirements of the TV bands. Cognitive radios are generally highly programmable radios that are able to opportunistically utilize spectrum and adapt their operating parameters based on the environment. Several white space device (WSD) operating requirements and adaptation techniques (e.g., for setting transmit power level vs. geo-location) have been previously proposed by the Commission. This paper discusses further levels of detail for several of the proposed operational rules and techniques. Major topics that are covered include geo-location databases, sensing-only WSD requirements, transmit spectral masks, and disabling beacon approaches.

This paper introduces several suggestions for TVWS unit operation, based on two generally defined equipment classes: Geo-location database-enabled CR WSDs and Sensing-only CR WSDs. Each class of device generally has different application spaces. For example, sensing-only devices are typically intended for lower-cost in-home consumer applications, while geo-location enabled devices are typically intended for higher-powered radio applications. As such, each class of device would have different operating requirements, as described below.

2 Geo-location Database-Enabled CR Device Comments

Motorola strongly supports the use of geo-location databases by CR WSD units.[1] Out of the range of currently available interference avoidance approaches for WSDs, geo-location databases provide the highest level of protection for licensed incumbents, and readily allow interference issues to be addressed in fielded WSD units in a timely manner (through nominal periodic database updates). The use of a geo-location database ensures that WSD units cannot operate within the defined protected service contours of licensed TV stations, thereby offering the greatest level of protection to broadcaster rights. Sensing-only WSD units cannot guarantee

[1] A geo-location database incorporates licensed incumbent transmitter (e.g., TV transmitter) parameters, CR operational rules, and the CR unit's operating location to determine a maximum allowable CR system transmit power level per channel (per location), to avoid harmful interference.

the same level of protection, due to the wide variety of unforeseeable operating and propagation conditions (e.g., fading, shadowing, antenna gain/height/polarization, etc.) encountered in the field. Geo-location databases can also maximize the potential use of unused TVWS spectrum (see below). Motorola has successfully demonstrated the use of geo-location databases that utilize currently available FCC TV transmitter database information, in an 802.11a-based live streaming video demonstration system.[2] The developing IEEE 802.22 standard also strongly supports the use of geo-location databases to determine allowable TVWS operating regions and frequencies.

Geo-location databases are derived in a manner similar to the traditional (time-tested) TV station frequency planning process: by applying the appropriate co-channel and adjacent channel protection ratios based on the operating locations and protected service contours of the transmitters. Location aware CR units are able to effectively perform similar computations (either in real-time or by storing the results in a local geo-location database) to avoid causing interference to licensed services (e.g., TV reception). Motorola largely agrees with the Commission's proposed rules for setting TV receiver co-channel and adjacent channel protection ratios and maximum allowed CR system transmit power levels.[3] The Commission's proposed rules can be effectively utilized to simultaneously provide excellent protection to incumbent systems and determine maximum allowable CR TVWS system transmit power (EIRP) versus operating location.

2.1 Protection Determination

Motorola supports the use of FCC CURVES TV signal propagation computations[4], and modeling traditional (readily available) TV transmitter parameters (i.e., TX coordinates, ERP, antenna HAAT/RCAGL, antenna patterns, FCC service codes and their well-defined protected service contour levels) to determine the protected service areas of licensed TV broadcasters. Specifically, we support the following TV signal propagation models:

- for computing the protected Noise Limited Contour (NLC) for DTV stations, the use of F(50,90) propagation curves;
- for computing the protected Grade B service contours of ATV stations, the use of F(50,50) propagation curves; and
- for computing DTV and ATV signal strength within protected service contours, the use of F(90,90) propagation curves is supported for adjacent channel operations.

Motorola believes that any more detailed terrain-based propagation modeling (involving large detailed stored terrain databases), other than incorporating TV transmitter height above average terrain as already prescribed, would be computationally and cost prohibitive for typical CR units and is not necessary to adequately protect the broadcast service. Instead, Motorola

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[2] An end-to-end broadband TVWS communication system using a geo-location database was demonstrated to FCC staff on August 30, 2007 [See Motorola August 31, 2007 Ex Parte filing]. The FCC already maintains a detailed online database of TV transmitter information (called CDBS).

[3] The Commission's proposed rules for computing allowable CR system transmit power are described in ET Docket No. 04-186, "*Unlicensed Operation in the TV Broadcast Bands*", 5/25/04, pp. 14-18.

[4] See http://www.fcc.gov/mb/audio/bickel/curves.html.

proposes other techniques for dealing with non-average terrain and interference effects (see below).

Motorola, supports the Commission's proposal to allow CR WSD operation outside of protected service contours.[5] The use of nearest protected service contour edge modeling for computing CR system-induced interference into TV receivers is supported, which is conservative with respect to the protection of TV broadcast services.[6] Furthermore, when computing CR induced interference levels into TV receivers for adjacent channel and co-channel interference calculations, the extremely conservative assumption is made that the CR signal is seen with the full front-lobe TV receiver antenna gain (i.e., approximately 12 dBi typical antenna gain for distant contour-edge UHF DTV receivers), even though the interfering CR signal is likely received at greatly reduced power levels, since it is typically off-axis in the back-lobe of the TV receiver antenna pattern when originating from outside of the TV station's protected service contour.[7] Thus, the TV broadcasters will typically gain an additional 14 dB of interference protection near the edges of their protected service contours. This additional protection level may be relaxed if the interference protection is deemed to be excessive. Motorola also supports CR WSD operation within adjacent channel service contours in agreement with the Commission's proposed rules, provided that the appropriate interference protection levels are utilized. As described earlier, Motorola has illustrated the cost-effective use of geo-location databases using standard TV transmitter parameters and proposed WSD operational rules in a demonstration system.[8]

In regards to CR WSD generated interference levels and signal propagation, the proposed use of F(50,10) propagation curves (for co-channel interference) and F(50,50) propagation curves (for adjacent channel interference) is supported for CR unit antenna heights at or above 30m. For CR unit antenna heights below 30m, or for propagation distances less than 1.5km, it is suggested that the Commission adopt the use of relatively computationally simple and conservative two-ray CR signal propagation models to approximate F(50,10) propagation curves.[9] Note that use of the two-ray model essentially results in conservative (free-space) square law propagation losses for short propagation distances (see Appendix A). The WSD transmitter's adjacent channel splatter levels should also be fully accounted for when determining maximum allowable transmit power levels. Thus, when operating on adjacent channels, both the CR unit's on-channel emissions (which appear as adjacent channel

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[5] The Commission's proposed rules allowing WSD operation outside of protected service contours are described in ET Docket No. 04-186, "*Unlicensed Operation in the TV Broadcast Bands*", 5/25/04, pp. 14-16.

[6] Nearest protected contour edge modeling involves modeling not only the direct path from the TV transmitter to the CR unit's operating location, but also indirect paths from the CR unit to nearby points on the protected service contour.

[7] Typical front-back protection ratios for high gain UHF DTV antennas are 14dB – see OET Bulletin 69, "*Longley-Rice Methodology for Evaluating TV Coverage and Interference*", 2/6/04, pp. 7-10. Note that the typical TV transmitter planning process *does* take into account directional TV receiver antenna discrimination, which further reduces interference levels. Currently, CR system interference calculations do not rely on this beneficial effect.

[8] A low implementation cost geo-location database-enabled broadband TVWS communication system was demonstrated to the Commission on August 30, 2007 [See Motorola August 31, 2007 Ex Parte filing].

[9] Two-ray propagation models take into account operating frequency, transmitter and receiver antenna heights. See Appendix A for more details.

interference to the adjacent channel TV station), and the CR unit's adjacent channel emissions (transmitter splatter, which appear as co-channel interference to the adjacent channel TV station) should be modeled, such that a CR unit with higher adjacent channel splatter will have lower maximum allowed transmit power levels.

Motorola notes that the proposed CR-to-DTV adjacent channel D/U protection ratios (of -26 dB (upper channel) and -28 dB (lower channel)) are on average 6 dB greater than the ATSC recommended -33 dB adjacent channel D/U level contained in the ATSC Receiver Guidelines document (A/74, referenced below), thereby providing additional adjacent channel protection to TV reception (assuming that CR adjacent channel emissions are adequately controlled). Also, the Commission's recent DTV receiver interference rejection report showed that several typical DTV receivers had even better adjacent channel rejection performance with weak desired DTV signals than the ATSC (A/74) -33 dB recommendation, with adjacent channel D/U ratios ranging from approximately -38 to -42 dB.[10] Furthermore, the use of F(90,90) propagation curves for computing TV signal strengths inside of adjacent channel contours tends to conservatively reduce predicted incumbent TV signal levels by more than 10 dB towards the outer areas of typical protected service contours. As in the case above, the conservative (worst case) assumption is made that CR signals originating from within adjacent channel protected service contours see the full front-lobe TV receiver antenna gain. Thus, Motorola believes that there is adequate adjacent channel protection for TV receivers, including a significant safety margin, built into the proposed WSD operating rules, and that CR units will be able to safely operate within adjacent channel contours without causing harmful interference to TV broadcasters. Motorola notes that disallowing CR operation inside of adjacent channel contours would greatly reduce the public benefit for the TVWS (especially near major metropolitan areas). Therefore, Motorola strongly urges the Commission to allow CR WSD operation inside of adjacent channel contours as was originally proposed. Note that the use of "mirrored" incumbent databases (described below) allows the Commission to quickly and readily address unintended interference effects, should they arise from TVWS operations.

2.2 Database Approach Advantages

Use of a geo-location database as the principal means of determining the operating parameters of a WSD has a number of critical advantages. This approach not only provides highly reliable protection of incumbents, it will also result in more efficient use of the white spaces. In addition, it provides a regular link to deployed devices that can be used to adjust protection requirements over time if necessary, to introduce new services, or to provide priority among devices if desired.

Motorola strongly believes that the use of geo-location databases will provide the most efficient TVWS spectrum utilization when compared to sensing-only WSD units. This is in part due to the very conservative sensing/incumbent detection thresholds that must be placed on sensing-only WSDs to ensure incumbent protection over a wide variety of operating conditions. Geo-location database-enabled WSDs are able to more efficiently and much more accurately pre-determine the protected service areas of licensed incumbents based on device operating location.

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[10] See OET report FCC/OET 07-TR-1003, "*Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006*", 7/31/07, p. 5-12.

Also, the use of TV transmitter antenna pattern data and actual protected service contour levels (e.g., for low-power TV transmitters) has significant benefits in terms of efficiently utilizing available spectrum and increasing spectrum access. Sensing-only approaches will not have the benefit of such knowledge.

The use of geo-location databases offers several other key advantages compared to other approaches. It is assumed that geo-location-enabled CR WSDs will periodically access (e.g., approximately weekly, daily or at whatever interval the Commission deems appropriate) the incumbent databases, such as those similar to the FCC's CDBS of TV transmitter information, and recompute maximum allowed WSD transmit power levels vs. operating location. This normal update process in effect provides a critical control link to fielded WSD equipment, in which operational updates (to rules, protection requirements, incumbent transmitter types, etc.) can be effectively communicated to CR WSD units. Having a routine update process in place also readily allows for WSD unit registration (and even the gathering of past CR unit operational information, if desired). Such mechanisms could allow easy tracking of interference issues in the field. Even the required update rates themselves could be specified in the periodically accessed database, allowing for more rapid changes if conditions warrant.

It is not strictly necessary for the Commission to specify the exact means of accessing the database. It is anticipated that most CR units will typically access the incumbent database via an internet connection, however, such information could also be broadcast in data sub-channels of DTV stations, or communicated through other means as appropriate. The critical component is that CR WSDs are able to periodically access the database and receive updated information. If a geo-location-enabled WSD unit for some reason is unable to make timely periodic (e.g., weekly) access to the incumbent databases, it should be required to lower its maximum allowable transmit power level down to that of an unlicensed sensing-only CR WSD unit after a period of time (and rely on the same incumbent detection thresholds of those units). This type of protection mechanism ensures that safe WSD system operation will be maintained under a variety of scenarios.

Importantly, the use of a periodically accessed incumbent database readily allows new stations and services to be added into the database, thus providing additional future protection. For example, known (and stable) licensed wireless microphone deployments (e.g., around sports stadiums, theatres, etc.) could easily be added into the incumbent database. Similarly, actual land mobile radio (LMR) and commercial mobile radio (CMR) transmitter sites could be noted in the database and provided site-specific protections. Just as different classes of TV transmitters (e.g., full-power DTV (DT), low-power digital (LD), TV translators (TX), etc.) have different protection requirements, new classes of protection requirements could readily be incorporated into the incumbent database (for both transmitters and receivers). Typical specifications for an incumbent system include: transmitter operating location/coordinates, protected service contour levels, incumbent signal propagation model (e.g., F(50,50), F(50,90), etc.), ERP, antenna HAAT/RCAGL values, known antenna patterns/rotation (if any), and incumbent receiver protection ratios (e.g., co-channel, adjacent channel, and possibly alternate channel protection requirements, etc.). The use of a fixed framework of specifications would make adding new services (and service codes) relatively straightforward.

Furthermore, the concept of employing "mirrored" incumbent databases for TVWS system usage can be highly beneficial. The basic concept involves copying known incumbent databases (e.g., of TV transmitter parameters, wireless microphone deployments, etc.) and

protection requirements into a mirrored incumbent database that TVWS systems exclusively utilize and periodically access. Having this mechanism in place allows regulatory officials (or their designated managers) to effectively address interference issues in the field, on a near-real time basis (e.g., weekly or daily). For example, assume that a particular TV station was experiencing interference from TVWS units in its western viewing areas. The affected station's antenna pattern used for to determine the protection provided by TVWS units could be readily modified (i.e., increased in the western areas to expand the protected service contour) in the mirrored incumbent database to effectively address the interference problem in the field (since TVWS units would periodically pick up these database updates, and naturally incorporate the incumbent transmitter parameter changes into their typical protected service area computations). Similarly, co-channel, adjacent channel, and alternate channel (if any) protection ratios could be modified (within reason) for the station type (i.e., service code) or receiver type (e.g., DTV, ATV, etc.), and stored in the periodically accessed mirrored database. (The granularity of such information may be global, or could even be extended down to the per-station level if desired.) These techniques can be utilized to efficiently account for non-average (non-modeled) terrain variations in the field. Even the allowed interference radius value could be added into the database, allowing differing radii for different types of geographies (e.g., rural, city, etc.). Another example of providing additional interference protection might involve the establishment of keep-out zones around CATV headend OTA-DTV receiver sites (that may be located outside of typical protected noise limited contours), which would provide practical protection to thousands of cable viewers. Perhaps most importantly, the mirrored database approach allows regulatory officials (or their designated database managers) to address WSD device operation once fielded, either to increase or relax protection levels provided to incumbents in the field. Significantly, the additional implementation costs of utilizing mirrored database techniques in geo-location database-enabled CR WSDs are extremely low, since most of the required computational mechanisms are already in place for such units.

Motorola recommends that the database be maintained by a third party coordinator. Similar to the approach for other services, such as land mobile radio, where third parties maintain a database and coordinate channel use to avoid interference, Motorola believes that a third party coordinator will be best positioned to maintain the database and to make adjustments in a timely manner in response to information obtained from operations in the field. Also note that the Society of Broadcast Engineers, for example, is known to coordinate Part 74 wireless microphone deployments in some areas. This type of information may be combined in incumbent databases to provide a very high level of overall protection. Motorola notes that the existing data contained in the Commission's TV transmitter database (CDBS)[11] is sufficient to provide protection to incumbents.

2.3 CR WSD Unit Location Accuracy Requirements

Motorola believes that the location accuracy levels cited by the developing IEEE 802.22 standard are appropriate. Specifically, 802.22 cites a required CR unit location accuracy of 300m, with 95% confidence level. This level of accuracy allows numerous low-cost methods of

[11] The Commission's CDBS TV transmitter database is available online at: http://www.fcc.gov/mb/audio/tvq.html.

determining unit location to be utilized.[12] This level of accuracy is also deemed appropriate since predicted TV signal strength levels do not generally change very rapidly over a 300m distance. One would expect that geo-location database spatial resolution (e.g., if pre-computed and stored) would be at the same or higher levels of resolution. Such decisions impact the implementation costs of stored geo-location databases. For example, with a 300m spatial grid resolution, a stored geo-location database covering a 50 km x 50 km operating area could be stored in roughly 1 MB of memory (a reasonable figure)[13]. Note that location uncertainty techniques could be applied (described below) to reduce the storage or accuracy requirements even further (especially for typically less utilized geographic areas).

The intent of location uncertainty techniques is to perform maximum allowed CR transmit power level computations at a higher spatial resolution, and reduce the resolution down to lower levels by taking the worst case (i.e., minimum allowed transmit power) operating level over the appropriate neighboring higher spatial resolution geographic points. For example, if 50m spatial resolution maximum allowed transmit power levels are computed, but 500m stored geo-location database resolution is desired, each stored 500m resolution point could be determined by taking the minimum of power levels over any higher resolution (50m) point within 250m of each resulting 500m point. Such a technique would allow CR equipment manufacturers to trade off geo-location database storage requirements for reduced maximum allowed transmit power levels, while still meeting minimum implied geographic spatial resolution requirements set by regulations. Taken even farther, such techniques could allow maximum transmit power levels to be accurately (and safely) determined for wide geographic areas (e.g., a town-wide region). These computations should always take into account the worst operating point (for the CR unit) within the contained region (such that if a protected incumbent service contour is contained anywhere within the region, operation would be prohibited on that channel for the entire region). Such techniques also allow variable resolution geo-location databases to be stored (with high resolution in typical operating areas, and lower resolution in less utilized operating areas), in order to cover very large operating areas (e.g., to enable nationwide coverage for Federal Agency radios).

2.4 Transmit Power Level Requirements

Considering that geo-location databases effectively protect incumbent systems based on device location, Motorola believes that there is no reason to limit their use to fixed access WSD systems. The use of a geo-location database for highly effective incumbent protection can be incorporated not only into fixed access devices, but also into portable and mobile WSD devices. Motorola believes that professional-use CR units employing location capability and geo-location databases should be allowed to transmit up to 36 dBm maximum EIRP power levels (with actual operating levels taking into account unit location and location accuracy). This includes location-enabled fixed-portable CR devices (e.g., a vehicle mounted local area coverage system), location-enabled CR portable devices (e.g., enterprise and land mobile radios), and tethered

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[12] See the IEEE 802.22-07/0248r12 and IEEE 802.22-06/0159r10 "*Geo-location with Database Requirement Development*" documents (particularly Section 6.5 of the latter), available at: http://www.ieee802.org/22/

[13] Specifically, a 167 pt. by 167 pt. location grid would be required to cover a 50.1km x 50.1km area, and the resulting max. allowable CR transmit power levels for each location (covering channels 14-51) would require 38 bytes each, for a total of 167 x 167 x 38 = 1,059,782 bytes of memory to contain the geo-location database results.

portable CR devices (defined below). It is anticipated that many of these devices will be used on a transient (temporary) basis. This class of device is expected to be targeted toward professionally installed and managed devices.

2.5 Tethered Portable CR WSD Operation

A tethered portable CR device is defined as a unit that does not directly possess location determining (or geo-location database) means, but has communications access to a location-enabled (and geo-location database-enabled) base station broadcast control signal. This tethered CR WSD-enabling control signal (or enabling beacon) can be utilized to inform the tethered portable unit of the allowed operational channels and their respective maximum allowed transmit power levels for the operational region of interest.[14] A geo-location database enabled base station can estimate a conservative (i.e., maximum possible) WSD system coverage area (e.g., based on its allowed transmit power level, operating frequency, and conservative propagation rules) and reference a geo-location database in order to determine maximum allowable WSD transmit power levels (per channel) over the conservatively estimated coverage area. By applying the location uncertainty techniques described above, the overall maximum allowable CR system transmit power over the coverage region would be limited to the minimum allowed (i.e., lower bound) transmit power over the entire potential WSD operating region in the geo-location database. That is to say, all higher spatial resolution geo-location database points/coordinates contained within the potential CR WSD operating locations/coverage area would be examined, and the lowest allowed transmit power level would be selected per channel, and broadcast over the enabling control signal to tethered portable units.

This straightforward approach ensures that a tethered CR WSD operating anywhere within the potential CR system coverage area obeys the maximum allowed transmit power level limitations for the entire region/set of locations. The approach is essentially the same as having a geo-location enabled WSD whose operating location is expanded to a set of potential operating locations (a CR system operating region), and the worst case operating location (i.e., lowest transmit power database point) is chosen for that region and globally applied in order to ensure protection to licensed incumbents. In cases where the CR system's coverage area is smaller than the required location resolution (e.g., say, 100m for a WLAN TVWS system), no additional geo-location database points would need to be examined (e.g., the AP could just broadcast the available channel list and power limits for its current location). Any tethered WSD that loses communication with the geo-location database control signal would be required to reduce it's transmission power to that allowed by a sensing-only WSD after a predetermined period of time.[15] In such a case, the un-tethered WSD would be required to rely on the specified incumbent detection sensing levels to detect incumbents, and would operate as would any typical sensing-only CR WSD.[16]

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[14] This approach is similar to the enabling control signal technique that the Commission proposed in its NPRM, ET Docket No. 04-186, "*Unlicensed Operation in the TV Broadcast Bands*", 5/25/04, p.10.

[15] The device would operate at its previously determined maximum permitted power as long as it remains in intermittent communication with the associated base station with periods of interruption that are less than some predetermined time as specified by the Commisison.

[16] If the WSD does not have sensing capabilities then the device would stop all transmissions.

These same set of techniques allow a CR system to effectively address portable unit mobility issues (by expanding the potential operating region around a mobile unit), and allow CR WSDs to operate anywhere within predefined geographic regions (assuming that very coarse location determining means are available), while ensuring that WSD transmit power levels are no higher than their fully location-enabled fixed access counterparts. Thus, if one accepts that safe, interference-free operation of geo-location-enabled fixed access CR WSD systems can provide sufficient protection to incumbent operations, one should also accept that the approach extends to the safe operation of their (directly and indirectly) location-enabled CR WSD counterparts. Note that in all of the above cases, WSD unit antenna gains and heights should be properly taken into account when computing interference effects.

2.6 Protection Enhancement by Sensing

Geo-location database techniques can be combined with spectral sensing to provide multiple levels of protection. It is expected that CR units utilizing geo-location database techniques will possess spectral sensing capability anyway, in order to rank-order the quality of available channels. This typical ranking process ensures that channels with unexpected incumbent transmissions will generally be avoided (since they will be ranked lower due to the interference levels on the channel). Motorola demonstrated this concept during its geo-location based CR system demos, where an available channel with an unexpected TV signal was ranked lowest in the channel listing.[17] In the case of a geo-location enabled WSD, however, sensing is not the primary means of protection given the greater accuracy of the geo-location database in determining protected incumbent service areas. Accordingly, geo-location enabled units should not be required to abandon channels where weak TV transmissions are sensed above the specified sensing-only WSD thresholds, but where the database indicates operation is acceptable. This will help avoid spectrum lying fallow in cases where the channel is usable but, for instance, certain anomalous atmospheric propagation effects allow a low level TV signal to be sensed. While the use of these channels will typically be avoided because the background interference detected on the channel will result in a lower channel ranking, as the TV white space becomes more congested, the option to use the channel should remain. Other types of incumbent detection and sensing, such as for secondary licensed wireless microphone deployments, will still need to be performed in geo-location enabled units. An additional level of protection for such devices is provided by requiring WSDs to recognize a disabling beacon, as described in the IEEE 802.22.1 standard (and the *Disabling Beacons* section of this document, below).

2.7 Additional Database Information

As stated previously, although the general categories in the FCC CDBS TV transmitter database provide sufficient information to protect TV licensees, there is some ambiguity as to which authorizations must always warrant protection. A complete and specific listing of which FCC service codes and status codes to protect in the incumbent TV transmitter database would be helpful to avoid any ambiguity among equipment manufacturers as to which authorizations are to be protected. While it is clear that protection must be provided for licensed stations, the protection requirements of other FCC service and status codes are less clear (e.g., special

[17] A Motorola geo-location database-enabled broadband TVWS communication system that sensed incumbents was demonstrated to the Commission on August 30, 2007 [See Motorola August 31, 2007 Ex Parte filing].

temporary authority 'STA' status). Motorola has noted that a relatively small number of TV stations in the FCC TV transmitter database listed with "CP-MOD" (construction permit – modification) status are actively on the air and transmitting (often full-time), while a very small number of licensed auxiliary stations (e.g., with 'DX' service codes) are not currently on the air (and are likely intended only for emergency back-up use). A simple method to address such protection ambiguities would be to add a "Provide_Protection" (PP) flag to the incumbent database, to clearly indicate that the listed station is active and should be protected.

In addition, a unified set of propagation modeling code would be helpful to ensure uniformity of propagation modeling results among different TVWS equipment manufacturers. Currently, F(50,50), F(50,10) and F(50,90) propagation computation results can be verified via the online version of the FCC CURVES calculator, but there does not appear to be a similar reference F(90,90) curves modeling tool available. A unified method for modeling differences in CR unit antenna heights (compared to the 9m standard value for the F(l,t) curves) would also be helpful. Relatively computationally simple two-ray propagation models (as described above), or alternatively, small/medium and large urban HATA models may be useful for this issue (see references in *the Sensing-only CR Device* section below).

3 Sensing-only CR Device Comments

CR WSDs that rely on sensing only to determine spectral availability face several formidable regulatory and design challenges. The first (and possibly most important) task is determining an appropriate sensing threshold in order for the WSD to determine whether it is within an interference range of an incumbent receiver (which is used in making the decision whether or not to utilize the channel) .[18] Such thresholds depend heavily on numerous physical and operational variables, including CR unit antenna heights, gains, and polarizations, in addition to unit location (indoors/outdoors) and fading/shadowing conditions. Typically, many of these variables are uncontrollable (e.g., portable unit orientation and placement), resulting in a wide range of sensed signal levels in practice.[19] In order to effectively deal with such uncontrollable conditions, a conservative approach must be adopted to adequately protect spectral incumbents. These requirements dictate not only sensing for multiple incumbent types (e.g., DTV, ATV, wireless microphones, beacons), but also sensing across multiple frequencies. Sensing-only CR WSDs should be required to sense licensed signal levels on adjacent channels, in order to provide the proper level of protection to adjacent channel incumbents. Furthermore, because sensing is an inexact science due to the number of uncontrollable variables involved, Motorola proposes to limit maximum allowed transmit power levels for unlicensed sensing-only CR WSDs.

In order to analyze sensing levels we first examine the requirements based on a fixed access device deployed according to specific assumptions used in IEEE 802.22. Even though this type of deployment actually is proposed to rely on geo-location database methods, it is a

[18] Interference range is defined in this whitepaper as the minimum distance at which a TVWS device will not exceed the Commission's specified protection levels for broadcast TV operations.

[19] See, e.g., OET report FCC/OET 07-TR-1003, "*Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006*", 7/31/07, Table 2-4, p.2-7.

good starting point to understand the levels of protection required and associated parameters to ensure detection of the TV signals. We then apply this analysis to the variances that would be experienced as portable devices are introduced into the deployment plan. Finally, we comment on direct pick-up effects, sensing adjacent channel operations, NTSC TV sensing and wireless microphone sensing.

3.1 Fixed Access Sensing Levels

In IEEE 802.22, the broadcaster participants have suggested a sensing threshold for DTV signals of -116 dBm for a horizontally polarized (nominally 0 dBi, professionally installed) external roof-top sensing antenna mounted at 9m height.[20] Although 802.22 systems plan to rely on a geo-location database to determine available channels, let us assume that only sensing is relied upon for the following analysis. The -116 dBm level corresponds to approximately 17 dBu E-field strength at 600 MHz, which is some 24 dB below the 41 dBu minimum usable UHF signal level at the noise limited contour (which accounts for the 8 dB difference between typical 8 dBi TV receiver antenna systems and 0 dBi sensor antenna system gain). This amount could at first glance appear to be an excessive margin. However, for sensing-only CR devices, it must be presumed that sensing reliability be much greater than the TV reception reliability, in order to adequately protect TV reception. That is, F(50,90) reliability may be adequate for DTV reception, but F(90,90) or greater reliability may be necessary for minimizing interference from sensing-only unlicensed radios. Beyond being more reliable, the reliability needs to apply out to the CR unit's interference range beyond the protected contour. This is best demonstrated by the following example.

Assume a typical UHF DTV transmitter has 200 kW ERP and 200 m HAAT. According to the FCC F(50,90) calculator, the protected contour range is 73.6 km. At this range, the E-field would exceed 41 dBu in 50% of the locations 90% of the time. See Figure 1.

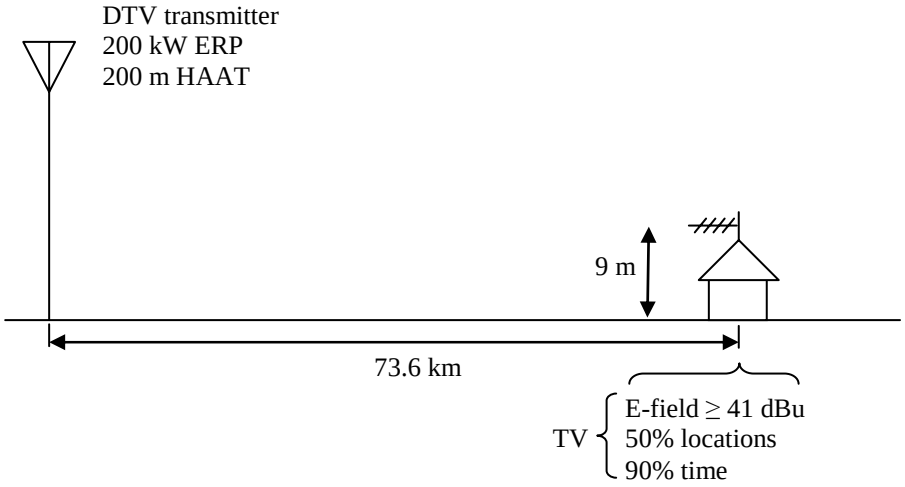

***Figure 1**. Protected contour range for example DTV transmitter.*

[20] *See*, e.g., IEEE 802.22-07/0074r2, "*The Spectrum Sensing Function*", Steve Shellhammer, March 2007, Section 9.1.3.1, Table 12. Available: www.ieee802.org/22.

For a DTV receiver, the Commission has proposed that the co-channel interference from unlicensed users should be 23 dB below the 41 dBu protected contour level, or 18 dBu.[21] The CR unit co-channel interference calculation is proposed to be based on F(50,10) propagation curves (for antenna heights at or above 30m). That is, the E-field at the interference range will exceed 18 dBu in 50% of the locations only 10% of the time – a very conservative model. In this example, the unlicensed CR interferer is assumed to be transmitting 4 W EIRP at an antenna height of 9m (e.g., from another residence). Note that ordinarily this EIRP would have some directivity away from the protected service contour (see Figure 2), and that the DTV receive antenna would also have some azimuthal discrimination against interference (resulting in a 14 dB interfering CR signal loss for a typical UHF TV receiver antenna due to the back-lobe response – see below).[22]

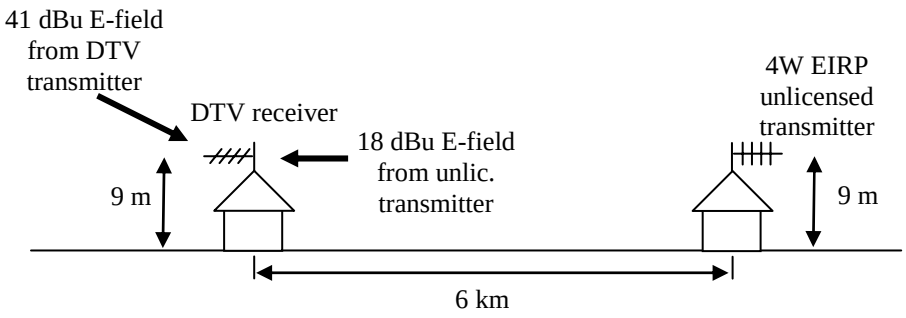

Figure 2. *Interference range from unlicensed transmitter.*

The 18 dBu interference range can be calculated to be 27.3 km using the FCC's F(50,10) calculator; however this result is highly pessimistic since: 1) antenna discrimination is neglected on both ends of the link; and 2) the FCC calculator's minimum transmitter height constraint is 30m, while the unlicensed transmitter's true height will only be 9m. A NTIA Longley-Rice path loss calculator[23] suggests that the pessimistic FCC F(50,10) model's 27.3 km interference range for a 30m transmitter height (with careful TX siting) corresponds to about an 18 km interference range for a 9m transmitter height (with random TX siting; both models use 9m receiver height and random receiver siting). It must be emphasized that the 18 km interference range calculated here is still extremely conservative, since it neglects antenna discrimination at both ends of the interference link and likely usage of cross-polarized unlicensed transmissions. For example, while the FCC F(50,10) calculator without antenna discrimination on either end predicts a 27.3 km interference range for 30m transmitter HAAT, with a 14 dB back-lobe discrimination in the UHF DTV receive antenna and 10 dB CR transmitter antenna discrimination,[24] the 30m

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[21] FCC 04-113, ET Docket No. 04-186, *In the Matter of Unlicensed Operation in the TV Broadcast Bands*, Released May 25, 2004, pp. 15-16..

[22] See OET Bulletin 69, "*Longley-Rice Methodology for Evaluating TV Coverage and* Interference", 02/06/2004, Table 6.

[23] http://ntiacsd.ntia.doc.gov/msam/ITM/itm.htm. Longley-Rice parameters for this example: 600 MHz, horizontal polarization, careful/random siting, 50m terrain delta, continental temperate, 50% confidence, broadcast variability mode, surf. refractivity = 301 N-units, gnd dielec. = 15, gnd cond. =.005 S/m.

[24] Effective EIRP directed towards protected contour is 26 dBm instead of 36 dBm, and allowed DTV co-channel interference level of 32 dBu (18 dBu + 14 dB) utilized.

transmitter height interference range is reduced from 27.3 to 6.3 km. The corresponding 9m Longley-Rice F(50,10) transmitter height interference range would be around 3.3 km. With DTV receive antenna discrimination only (i.e., with an omni CR transmit antenna), the interference range is 11 km for 30m transmitter height (using FCC F(50,10) models), and 6 km for 9m transmitter height (using the above Longley-Rice calculator for 9m equivalent height). It is assumed that this 6 km CR interference range model is the most realistic, since any reduction in TV receiver antenna discrimination (to less than 14 dB isolation levels) would be made up by typical fixed access CR unit antenna directionality away from the contour. Note that TV receivers that are able to successfully receive DTV transmissions at the edge of the protected service contour will almost certainly utilize these high gain, directional antennas. (Such CR interference models should not be assumed to be valid when operating inside of protected service contours though. IEEE 802.22 has proposed to not operate within adjacent channel contours, primarily due to the large anticipated coverage areas of the network.) This interference range could be further reduced if a cross-polarized (i.e., vertically polarized) unlicensed transmitter was assumed, though to be conservative this is also not pursued here. The 6 km CR unit interference range is assumed for the following analysis.

Now the sensing reliability levels may in principle be statistically determined both at the interference range beyond the protected contour and at the actual protected contour. This requires an F-curve calculator that has more capabilities than those currently available from the Commission, with functionality to determine the location and time reliability based on an E-field value and a range from a TV transmitter. This functionality can be approximated using the Longley-Rice calculator referenced above. For the interference range calculated above, the TV receiver is at approximately 74 km away from the TV transmitter and the CR interference contour is 6 km further out at about 80 km (see Figure 3). The FCC F(50,90) calculated signal at 80 km is 36.3 dBu, which represents a 19.3 dB margin above the proposed DTV sensing threshold of 17 dBu (-116 dBm). That is, the CR unit will be assumed to successfully detect incumbent signals that are 19.3 dB weaker than the F(50,90) predicted signal level at its present location. The equivalent location and time reliability figures for a DTV signal exactly at the 17 dBu detection threshold can now be found for the CR unit's location, to determine a statistical sensing reliability figure. Using the Longley-Rice calculator (with 200m TX antenna height and careful siting), a 19.3 dB equivalent path loss difference can be found at 80 km between F(50,90) and F(96,96) reliability (see below for full algorithm details). That is, a 36.3 dBu F(50,90) level (at the CR unit) also corresponds to approximately a 17 dBu F(96,96) (DTV detection threshold) level, or equivalently at the 80 km CR unit range, the E-field available for sensing would exceed 17 dBu at 96% of the locations 96% of the time.

This 96% sensing reliability level would appear to be an acceptable level for the realistic assumptions discussed above. In practice, a 95% location and 95% time sensing reliability level would appear to be adequate for most cases using realistic TV receiver antenna patterns. When combined with an independent probability of successful DTV sensor detection of 95% (which depends on the sensing algorithms and hardware employed), an overall DTV incumbent detection ratio of over 91% (0.96 x 0.95) would be achieved at the CR unit's location (at the edge of the interference radius). As the CR unit approaches the service contour, its incumbent detection probability will naturally increase. It is suggested that DTV sensor probability of detection rates be set no lower than 95% for the specified detection threshold (e.g., -116dBm). As an example of improved overall DTV detection, if the DTV sensing threshold was reduced to -120 dBm, 4 dB of additional path loss could be tolerated, resulting in 98% (location and time)

sensing reliability. When combined with a 98% DTV sensor probability of detection, an overall 96% DTV detection rate would be achieved at the 80 km interference range. It is important to note that as the CR unit operates closer to the protected service contour (presumably with less transmit power), its sensing reliability would increase, since the DTV signal of interest would also increase in strength, making detection more likely for a given DTV detection threshold.

A methodology that defines the required sensing reliability levels and then determines the required E-field strength would seem appropriate for defining fixed-access sensing thresholds. Motorola feels that a location and time sensing reliability level of at least (95,95) for the realistic TV receiver antenna discrimination model (given above), and a DTV sensor detection probability of at least 95% (e.g., down to at least -116 dBm input levels) would be adequate for fixed access sensing-only CR devices with external professionally installed antennas. Collaborative sensing techniques can significantly improve both the overall received DTV signal strength distribution and the DTV detection probabilities.

In summary, the steps for determining DTV sensing reliability (for a given DTV sensing threshold, and fixed access CR units with 9m external 0 dBi antenna heights) are:

1) For a variety of cases of ERPs and HAATs, determine the 41 dBu FCC F(50,90) UHF *DTV protected contour distance* (only one typical UHF DTV example has been used here – other bands and protected contour levels may also be utilized);

2) Determine *(9m TX) CR unit interference range* (e.g., using Longley-Rice height corrected F(50,10) curves) based on *CR transmit power level* (EIRP):

    a. Assume realistic interference range models at the edge of the protected service contour (e.g., 14 dB of TV receiver antenna discrimination). One could also rely on polarization discrimination or CR unit antenna directionality, but that is not accounted for in this description.

    b. Convert *CR transmit power level* (EIRP) to ERP level, and utilize the FCC F(50,10) calculator to compute *(30m TX) CR unit interference range* (distance to 18 dBu + 14 dB = 32 dBu tolerable DTV co-channel interference level, by setting TX HAAT = 30m, and using the appropriate band).

    c. Height correct the *(30m TX) CR unit interference range* to *(9m TX) CR unit interference range* by computing Longley-Rice F(50,10) path loss at the *(30m TX) CR unit interference range* (using 30m TX height, 9m RX height, careful TX siting, and random RX siting). Determine *(9m TX) CR unit interference range* by finding the equivalent Longley-Rice F(50,10) path loss by varying the distance, for both 9m TX , 9m RX height, random TX and RX siting (for both the CR transmitter and TV receiver).

3) Determine F(50,90) *DTV signal level* at CR unit interference contour (i.e., FCC F(50,90) E-field at edge of (*DTV protected contour distance + (9m TX) CR unit interference range*)

4) Determine if acceptable sensing reliability (e.g. (95,95)) is met for a given *DTV detection threshold* (e.g., -116dBm), utilizing Longley-Rice modeling:

    a. Determine sensing reliability path loss margin by subtracting the 17 dBu (-116 dBm) *DTV detection threshold* from the *DTV signal level* at CR unit. This level

corresponds to the amount that the Longley-Rice F(50,90) propagation model path loss (using the above parameters) may be increased to arrive to at least F(l,t) equivalent sensing reliability;

5) Determine if acceptable DTV sensing reliability goal is met (e.g., *l>95, t>95* from step 4a above). The *DTV detection threshold* may be reduced to increase sensing reliability levels.

These methods rely on allowed sensing-only CR device transmit power levels (which affects the device's interference range, and observed DTV signal strength levels). Of course, this method may be extended to other CR unit (external) antenna heights (within the limits of the Longley-Rice model, and after height correcting the FCC F(50,90) and F(50,10) propagation models using similar methods). Note that the Longley-Rice models are utilized here to only examine differences (i.e., deltas) between path loss values and (location and time) reliabilities. The above procedure may also be slightly altered to compute the required *DTV detection threshold* given target sensing reliability levels (*l*,*t*).

For the given DTV example, at the protected noise limited contour itself (at 74 km) the 17 dBu (-116 dBm threshold) E-field is 24 dB below the 41 dBu F(50,90) NLC value. Again using the Longley-Rice calculator, this E-field value corresponds to a protected contour reliability of around F(98,98). That is, at the protected contour of 74 km, the E-field exceeds the 17 dBu sensing threshold in 98% of locations 98% of the time, so sensing reliability (using this threshold value) would be excellent at the contour itself.

Due to the relatively high overall sensing reliabilities discussed above, Motorola generally supports the proposed -116 dBm sensing levels for fixed access CR devices with professionally installed (horizontally polarized) externally mounted roof-top sensing antennas. Of course, if TV receiver antenna directionality is not assumed in the analysis, the CR unit interference ranges dramatically increase, and hence allowable CR unit transmit power must be reduced to meet the same incumbent sensing reliability levels. This may be the case for fixed access consumer equipment (that is not professionally installed). For these reasons, high powered fixed access devices (e.g., IEEE 802.22 devices) are also expected to utilize geo-location database techniques to further ensure protection of licensed incumbents. Note that fixed access devices that transmit less power, and hence have shorter interference ranges, could in principle be allowed to relax their DTV detection thresholds somewhat to achieve the same sensing reliability. Alternatively, the DTV detection threshold could be held at the same level for lower transmit power units to improve overall DTV incumbent detection rates.

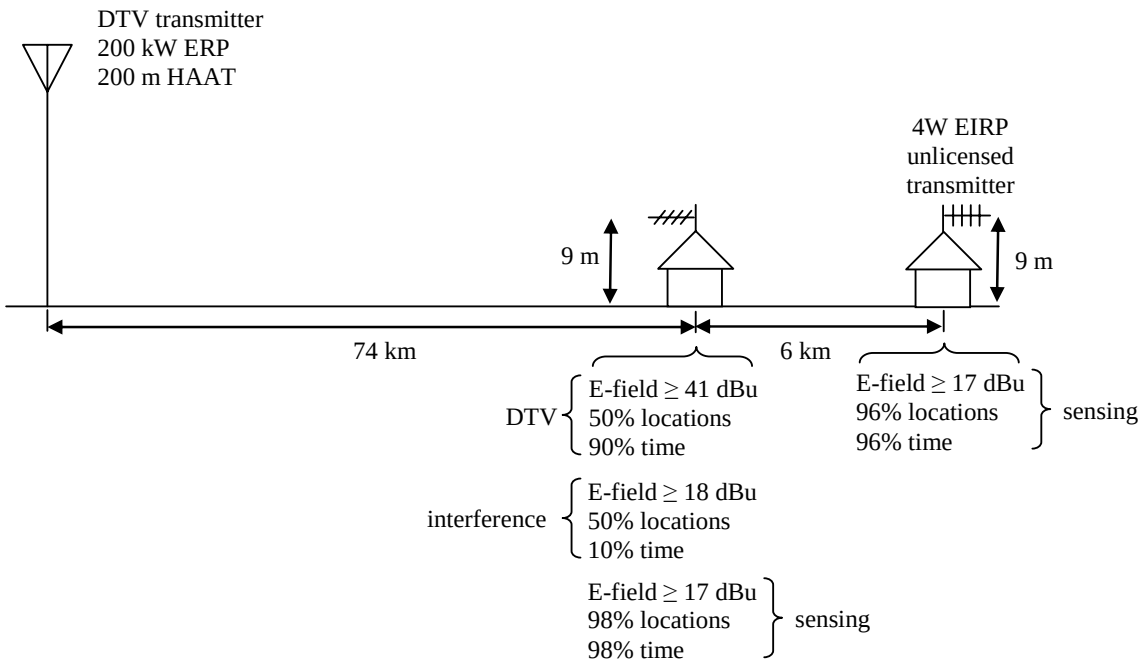

Figure 3. *DTV Interference and sensing scenario for the example system.*

3.2 Portable Device Sensing Levels

Portable devices (with smaller antennas, possibly indoor) face a much wider range of potential operating conditions. According to Hata models (referenced below), antenna height differences for portable units (compared to 9m fixed access devices) could easily result in 10-15 dB of signal reduction, in addition to antenna polarization and building penetration losses (with equally wide ranges). Therefore, it is likely necessary to reduce maximum allowed transmit power levels for sensing-only CR portables, and it may be necessary to decrease the required DTV detection levels (to below -116 dBm) to account for these differences. Reducing transmit power levels for portable (in-home) sensing-only CR devices has other benefits, such as reducing direct pick-up issues in the home, and reducing interference issues in the field should incumbent sensing fail to properly detect licensed spectrum users.

Broadcasters and unlicensed proponents working together in IEEE 802.22 agreed upon the -116 dBm sensing threshold for fixed access sensors with (nominally 0 dBi) external horizontally polarized antennas at 9m heights. For portables with antenna heights of perhaps 1.5 – 2m, the E-field signals that will be available will be at reduced levels compared to those at 9m, and will in general suffer some polarization mismatch as well. How much this E-field level differs will depend on the surrounding clutter. For small to medium sized cities, the well-known Hata model[25] indicates that the path loss correction for receive antenna height h_{rx} is:

$$C_h = (1.1\log f - 0.7)h_{rx} - (1.56\log f - 0.8)$$

[25] *See*, e.g., http://en.wikipedia.org/wiki/Hata_Model_for_Urban_Areas.

For f = 600 MHz and h_{rx} = 9m or 2m, the difference is 16.5 dB (i.e., weaker for 2m than for 9m). A 17 dBu field strength at 9m height that is used for fixed access sensing may only appear to a sensing portable at around 0.5 dBu (i.e., practically undetectable). Fortunately, some of the same effects that make portable sensing of incumbents difficult also work in favor of the portable CR unit in terms of inducing interference. These include lower antenna heights and building penetration losses. Unfortunately, these effects are not easily quantified, and the transmission paths from the TV transmitter to the affected TV receiver and the portable CR unit are even less likely to be similar than in outdoor fixed access cases. Therefore, it is recommended that directional TV receiver antenna discrimination not be included in any analysis of interference range. Thus, in order to ensure incumbent protection, portable sensing-only CR devices will need to limit their transmission power.

Once the other variables are fixed, the interference range ultimately depends on the portable transmit power level. Assuming 2m transmitter height and 9m TV receiver antenna height, 50% location reliability, 10% time reliability, 600 MHz, and FCC F(50,10) propagation with Longley-Rice height corrected EIRP:

Interference range (km)	FCC F(50,10) h_{tx} = 30m EIRP (dBm)	Longley-Rice corrected EIRP for 2m h_{tx} (dBm)
2.3	-6	+9.8
5	+8	+24.7

Table 1. *Allowed portable EIRP, based on 600 MHz Longley-Rice with (50,10) reliability and broadcast variability mode.*

where the offending E-field E = 8 μV/m (18 dBu, or 23 dB below the UHF DTV 41 dBu protected contour level), λ = 0.5 m (UHF), and reliability levels are 50% location, 10% time (these numbers will differ for VHF).

As in the case above, higher power portable sensing-only CR transmitters would require higher detection sensitivity to the TV signal since they have to detect the signal farther beyond the contour. The incumbent detection problem is also made difficult due to low portable antenna heights and gains (and polarization losses). A portable CR EIRP of +10 dBm would have an interference range of roughly 2.3 km. For the relatively low +10 dBm EIRP level with the DTV transmitter example used above, the 9m F(50,90) E-field strength at the CR interference range of 2.3 km beyond the contour (at 76 km) is 39.1 dBu, which would drop to about 13.7 dBu at a 2m sensing antenna height based on Longley-Rice height and reliability adjusted F(96,96) reliability as used for fixed access. Additionally assuming a realistic 3 dB polarization mismatch drops the available signal for sensing down to about 10.7 dBu field strength at 2m antenna height (e.g., roughly -122 dBm), approximately 6 dB below what is available for the 9m height at the 6 km fixed access interference range. This is only one example of what may be necessary for portable sensing-only CR devices, it is not an endorsement of a particular sensing threshold.

For portables that operate indoors, the signal to be sensed is further reduced by building penetration values of perhaps 5-20 dB or more, depending on the building construction and the depth into the building. This would push the threshold for sensing further down, however the

interference range would also be greatly reduced, as mentioned above. The challenge is determining what penetration loss values to assume for the TV signal coming into, and the unlicensed (interfering) transmit signal going out of the structure. The values will vary greatly depending on the CR unit location in the house (relative to the TV transmitter and affected TV receiver). Once again, there are no simple assumptions that can be made, since the variances involved are so high. Generally, these effects argue for more conservative allowed portable transmit power levels, and/or more conservative incumbent detection thresholds (as shown above).

Note that the values determined here are based on a single DTV transmitter example and only approximate calculations of sensing reliability. To determine the levels to be codified, further analyses should be performed with a variety of TV transmitter conditions for a defined sensing reliability (e.g. >95% time and location reliability for 2m antenna height) using a calculator that is consistent with the FCC calculators. Also, Motorola recommends performing more incumbent detection and interference field testing to validate the models and assumptions utilized.

3.3 Direct Pick-up Effects

CR system interference caused to ubiquitous consumer electronics equipment is also a major concern for fielded systems. According to CFR 47 Part § 15.118, cable ready devices should tolerate 100 mV/m interfering E-fields of horizontal polarization. For a given interference range, the maximum allowed EIRP resulting in a 100 mV/m E-field is

$$EIRP = \frac{E^2}{377} 4\pi d^2$$

which gives EIRP = 33 mW = 15.2 dBm for 10m interference range, and 10 mW = 10 dBm for 5.5m. The 15.2 dBm theoretical CR power limit result at 10m interference range lines up well with results found by the OET in their actual measurements (e.g., 15.3 dBm for 10m separation).[26] Note that in typical homes and apartments, it will likely be difficult to maintain a 10m CR device separation from cable devices and coax wiring, so a reasonable reduction in power (~5 dB) may be desirable (down to ~10 dBm) for in-home CR equipment to protect common consumer equipment from interference. Also, it is expected that the in-home coax wiring systems will be the weakest link with regards to interference susceptibility. Note that Motorola has conducted some initial in-home cable interference susceptibility testing.

Thus in general, portable CR in-home transmit power levels for should be held to a maximum level of 10 dBm EIRP to minimize direct pickup problems at the above interference range of about 18 feet (actual interference distances will depend on specific in-home cable system interference tolerance levels). It is important to note that most cable systems do more than just carry television broadcasts; they are also likely to carry high speed (internet) data traffic, potentially including VOIP phone service, so any interference impact could be wide ranging to the consumer. Motorola believes that the impact on consumer-grade electronics devices needs to be considered as rules for use of TV white space are developed.

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[26] *Direct-Pickup Interference Tests of Three Consumer Digital Cable Television Receivers Available in 2005*, OET, July 2007.

3.4 Sensing-only CR Adjacent Channel Operation

The above discussion in Section 3.1 and 3.2 covered the sensing and EIRP requirements for TV co-channel interference avoidance outside of protected service contours. Sensing-only CR operation on channels adjacent to TV stations is another possibility that will have to be considered for TVWS deployments.

For geo-location-based WSD operation, the methodology of computing the F(90,90) field strengths for adjacent channel TV signals at the CR location and setting EIRP based on the appropriate specified protection ratios (and propagation loss over an interference radius) will result in very high confidence that interference-free coexistence occurs between TV and CR systems.

For sensing-only based CR operation, the permissible EIRP will necessarily depend on sensed adjacent channel signals, in order to adequately protect adjacent channel TV stations (see *CR Device Transmit Masks* section below). To be appropriately conservative, it should be assumed that the strength of the E-field available to the TV antenna is the same as or perhaps even lower than the inferred E-field from the sensed signal. It's not hard to imagine a scenario where a portable CR device near a second story window would be exposed to nearly the same E-field as a neighbor's TV antenna on a single story house. Depending on spatial correlation for the E-field given the surrounding clutter and foliage, the E-field at the TV antenna may actually be slightly less than the portable-sensed E-field. However, without any universal models to rely on here, it is fairly difficult to specify the exact margin levels that will be required. Further study would be helpful to determine correlation values between rooftop TV antennas and sensed signal strengths in a variety of locations and orientations in the vicinity of the TV antenna. Similar to the co-channel CR operation power limits discussed above, adjacent channel operation power limits must also be set very conservatively to ensure adequate protection of licensed incumbents.

Note that the specified sensing-only CR WSD transmit spectral mask must also be well specified to avoid TX splatter problems into adjacent channels (and beyond). Otherwise, sensing of adjacent channels (and beyond) will be necessary to limit out-of-band emissions (see below).

3.5 NTSC TV Sensing

Sensing of low power NTSC TV signals will still be necessary after the February 2009 DTV transition date. Motorola supports the detection of NTSC signals down to -94 dBm levels (as supported by IEEE 802.22).[27] NTSC TV receivers also have much different (more stringent) interference protection requirements than DTV receivers (e.g., 34 dB co-channel D/U and -14/-17 dB adjacent channel D/U ratios), that must be taken into account. Similar sensing reliability methods to those described above can be applied for NTSC TV protection.

3.6 Wireless Microphone Sensing

In addition to sensing and identification of TV signals, certain wireless microphone operations also need to be protected. Directly sensing wireless microphones is possible, and IEEE 802.22 recommends a consensus threshold of -107 dBm in a 200 kHz bandwidth, which

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[27] *See*, e.g., IEEE 802.22-07/0074r2, "*The Spectrum Sensing Function*", Steve Shellhammer, March 2007. Available: www.ieee802.org/22.

corresponds to an SNR of 4 dB for 10 dB noise figure.[28] This value was viewed as a compromise or "best effort" that may not fully protect microphone deployments, depending on unlicensed EIRP and HAAT.

There are two problems with sensing wireless microphones (see also the Disabling Beacon section below). First, virtually any narrowband (<200 kHz bandwidth) unlicensed signal or unintentional emission within a TV channel could be mistaken for a wireless microphone transmission (leading to high falsing rates). In certain cases, it may be difficult to distinguish wireless microphones from other types of users (e.g., pilot or carrier signals in TV waveforms). Second, only a certain class of microphone use (Secondary licensed under CFR 47 Part 74 Subpart H) is entitled to protection under the Commission's rules. Sensing alone will not be able to distinguish between licensed and unlicensed operation, hence sensing-only unlicensed units may end up ceding spectrum to unprotected microphones or even unintentional emissions, diminishing spectrum access.

Long-term licensed microphone operations can be listed in a database (as mentioned in the *Geo-location Database* section above), eliminating the need for sensing. In other cases, it is better to have an over-the-air accessible supplement to the geo-location database (for more real-time or intermittent protection). This is the intent of the IEEE 802.22.1 beacon signal (see below), which provides database-like information such as location, identification/authentication, protected area, and channel usage. As with the other sensing-only situations, the sensitivity for detecting the beacon signal will be statistically related to the unlicensed unit's transmit power level.

The IEEE 802.22.1-developed beacon signal is a differential QPSK signal covered by an 8x spreading sequence with a chip rate of 76.87 kchips/s (as fully described in the *Disabling Beacon* section below). For 10 dB noise figure, 3 dB implementation loss, and 1% frame error rate chip SNR of 5 dB, the sensitivity of the beacon signal is nominally -107 dBm. The frame is composed of three information subframes. The first subframe contains the beacon database information, the second subframe the digital signature for authentication, and the third subframe the certificate for performing the authentication (as fully detailed below). The second and third subframes are only needed if the beacon signal is to be authenticated, and are not protected by an error correction code in the interest of keeping the frame repetition period short. Thus, there is an appreciable measure of security (against spoofing) contained in the IEEE 802.22.1 beacon approach.

3.7 Sensing-only CR Conclusions

Theoretically, incumbent sensing thresholds and transmit power levels are fundamentally statistically related for fixed access or portable sensing-only CR devices. Fixed access sensing-only CR units with external antennas are generally easier to analyze since the antennas are assumed to be rooftop height (and horizontally polarized), and reliable well-accepted propagation models are available. Portable sensing-only CR device operating rules should initially be very conservative on both incumbent sensing levels and the transmit power limits (as outlined above). Such rules can always be relaxed at a later date (once more test results and field

[28] A 200KHz noise bandwidth and a 10 dB NF results in a -111 dBm (-174 dBm/Hz + 10 log(BW) + NF(dB)) noise floor in the receiver.

experience is available). The real danger in not setting these limits at very conservative levels is that masses of unlicensed CR devices could be deployed in the market, with no good method for controlling or recalling them. (Incidentally, this is where geo-location database-enabled CR devices and mirrored database concepts excel, by offering outstanding levels of flexibility and future-proofing in fielded radios). Also, this is an area where disabling beacons (like the 802.22.1 concepts presented below) allow an additional level (or quite possibly the only level) of control over fielded unlicensed sensing-only CR devices (see details below). Thus, it is strongly recommended that the Commission require sensing-only CR devices to abide by a disabling beacon.

Due to the uncertain nature of sensing-only CR devices, and the need for further field testing, Motorola strongly recommends that sensing-only CR devices be prohibited from operating in TV channels 14-20 (due primarily to public safety interests in the band). CR devices that are aware of their location and protected markets may be able to operate on channels 14-20, as long as LMR/CMR operations in the band are adequately protected from interference. This is readily achievable through use of the geo-location database.

Motorola supports geo-location database-enabled fixed access devices transmitting up to 36 dBm EIRP, as is supported by IEEE 802.22. Motorola also supports use of the geo-location database to permit portable and mobile operation. For sensing only devices the final incumbent detection thresholds (and allowed transmit power levels) depend on the required sensing reliability and overall incumbent detection probability. This is in contrast to geo-location database approaches were the incumbent detection probability is based on location, and is essentially very highly accurate (with regards to protected service contours and allowed transmit power levels). Motorola would suggest taking a very conservative stance for sensing-only WSDs in order to ensure adequate incumbent protection

Due to the proximity of TVWS devices in the home cable environment we believe that allowed EIRP levels for sensing-only portable CR's of 10 dBm EIRP (for UHF) power limits is needed to protect from direct-pick up effects. Note that even at these low power levels, portable CR devices should be able to cover typical home layouts with broadband wireless data access (based on in-house propagation measurements and expected link budgets). Furthermore, even at these reduced power levels, portable sensing-only CR equipment should experience an increase in operational range over typical 2.4 GHz WLAN devices (roughly +16 dBm transmit power levels) due to approximately 12 dB less frequency-related path losses, and narrower receiver bandwidths.

Finally, testing of CR device incumbent detection algorithms should be rigorous, and well defined. For example, minimum probability of detection rates (e.g., 95% at the specified incumbent detection threshold levels) should be specified, and reasonable maximum probability of falsing rates should be specified (e.g., 10%) to ensure that CR devices' detection results are not artificially inflated. This approach would also help ensure reasonable spectral efficiency. Furthermore, these rates should be essentially immutable, such that they do not vary over time or actual operating conditions. Testing of incumbent detection performance should be done in realistic environments, with both static channel conditions as well as (e.g., frequency selective) faded channel conditions. There are a wide variety of multipath fading models (such as those

suggested in IEEE 802.22) available in the industry for such testing.[29] Realistic fading models will help identify real-world weaknesses in particular incumbent detection algorithms.

4 CR Device Transmit Masks

It is generally recognized that over-the-air TV reception can be harmfully impaired by unlicensed emissions that degrade either the high end or low end of the TV receiver's dynamic range. Typical input signal levels into DTV receivers range from -83 dBm to -8 dBm.[30] A strong off-channel signal presented to the TV receiver can limit its sensitivity due to a number of mechanisms discussed briefly below, while off-channel emissions from an unlicensed transmitter that fall co-channel to the TV signal can effectively increase the local antenna and receiver noise floor. The effective and reliable management of both impairment mechanisms is the responsibility of white space cognitive radios to ensure coexistence while simultaneously increasing spectrum utilization.

The CR device's transmit spectral mask will define how much power spills into the adjacent channels and beyond. The main criteria that must be satisfied while operating in the TVWS environment is that the CR transmissions not harmfully impair licensed signal reception. There are two types of CR emissions that can impair a licensed TV receiver:

1. The pass band level of the CR modulation exceeds the TV receiver selectivity limits (which could be due to limitations like front-end overload, phase noise/reciprocal mixing, filter selectivity, or nonlinear effects like intermodulation/cross modulation); and
2. The CR unit's out-of-band emissions (OOBE) fall co-channel with the licensed incumbent signal and directly degrade the C/I+N. This could be due to adjacent channel emissions (N±1), alternate channel emissions (N±2), or beyond (N±3…).

Impairments of the first type are due to limitations in the TV receiver, while impairments of the second type are due to limitations in the CR transmitter. Only the second type of impairment is under the direct control of the CR user, though power control based on geo-location database techniques and required incumbent protection ratios (e.g., TV co-channel and adjacent channel) allows harmful-interference free operation to be realized. Essentially, geo-location databases provide invaluable knowledge about expected TV signal strength versus location, and estimation of path loss to the nearest affected TV receiver enables a geo-location enabled CR unit to adjust its transmissions so as to not exceed specified TV receiver performance limitations. Sensing-only CR devices will not benefit from such techniques; therefore, their emissions must be carefully controlled (as described below).

The awareness and estimation of the licensed signal levels in the vicinity of the cognitive radio is addressed elsewhere in these comments.[31] There, Motorola recommends geo-location

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[29] *See*, e.g., IEEE 802.22-05/0055r7, "W*RAN Channel Modeling* ", Sofer et. al., 8/30/2005. Available: www.ieee802.org/22

[30] See OET report FCC/OET 07-TR-1003, "*Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006*", 7/31/07, p. 4-2.

[31] *See* the *Geolocation Database* section above, for a discussion on estimating field strengths to calculate max. allowed CR transmit power levels.

techniques be used, though sensing techniques may also be utilized in conjunction with database methods. Motorola believes that it is essentially a matter of spectrum accessibility – geo-location techniques will give high confidence of the local licensed signal strengths, while sensing radios will have lower confidence and hence must assume a more conservative stance with their transmissions. Either way, it's important to note that the EIRP that is determined by the cognitive radio is a maximum EIRP, and that the actual EIRP used should only be enough to cover the link budget for the application plus reasonable fade margins. A high-confidence awareness of the TV signal strength in the vicinity allows the CR unit a higher maximum EIRP level with conservative but practical off-channel emissions levels that satisfy both the TV receiver off-channel and co-channel D/U ratios, and provides adequate communication ranges and/or capacities for the CR application.

Whether the cognitive radios are geo-location database or sensing-enabled, estimating the proximity to the hidden-node[32] licensed receivers is a challenge, but it can be managed effectively by assuming a conservative interference range. The Commission has implied an allowed interference range of 10m,[33] reasoning that devices within 10m of the unlicensed transmitter would be under the unlicensed operator's control. Certainly this range will vary in practice, as mentioned above. In rural areas it may be unusual for neighbors to be closer than 500-1000m apart, while more densely populated areas could see spacing more on the order of 5m in home environments. In mobile applications, vehicles may not typically come closer than roughly 20m actual separation to a 9m-height rooftop mounted TV antenna.

Assuming DTV sets are designed per ATSC Document A/74 recommended D/U ratios going forward,[34] an example *ideal* spectral mask based on the recommended D/U ratios is shown below in Table 2.[35] These levels would allow the CR device to transmit the maximum EIRP without exceeding the Type 1 TV receiver impairments (above) while still satisfying TV co-channel interference levels due to the CR splatter. In this table, N is the active operating channel for the CR, and the indicated offsets in column 1 indicate the (6 MHz) channel offset from the operating TV channel. The actual minimum tolerable D/U ratios will be up to the discretion of the Commission, and in practice could be listed in the incumbent database to maintain some control over interference levels encountered with deployed CR systems. D/U ratios in the incumbent database could readily be adjusted to address interference issues in the field, as mentioned above. For sensing-only radios that do not have access to D/U ratios in a database (or otherwise), a nominal conservative profile should be assumed, along with off-channel sensing techniques. It is recommended that the Commission adopt the A/74 D/U ratios in practice, and specify which channel offsets need to be observed (for both the cases of geo-location and sensing-enabled WSDs).

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[32] Hidden in the sense that TV receivers only receive and don't intentionally transmit.

[33] *See* Footnote 50 of the May 2004 NPRM, "Field strengths within 10 meters of the unlicensed device may be ignored since it could be assumed that this region would be under the unlicensed operator's control."

[34] *See* ATSC Document A/74, *ATSC Recommended Practice: Receiver Performance Guidelines*, 18 June 2004. See also OET Report FCC/OET 07-TR-1003, *Interference Rejection Thresholds of Consumer Digital Television Receivers Available in 2005 and 2006*, 30 Mar 2007.

[35] With the exception of the adjacent channel, which is based on the Commission's original recommendations for adjacent channel D/U ratios in the original FCC 04-186 docket.

Note that the Commission currently specifies (ATSC and NTSC) TV receiver co-channel and adjacent channel (D/U) protection ratios for maximum allowed CR WSD transmit power computations. Thus, geo-location databases must take into account both on-channel emissions and incumbent TV stations as well as upper and lower adjacent channel emissions and TV stations (as fully discussed above). As an example, for a CR operating on TV channel N=27 with a DTV signal on channel 26 (N+1 adjacent channel. receiver specification), the CR unit should adjust its EIRP based on the computed (Ch. 26) DTV signal strength knowledge and assumed path loss to a victim DTV receiver to satisfy the -26 dB D/U ratio at the TV receiver. To present this large of an off-channel interferer to the TV set, the CR transmitter adjacent channel emissions must satisfy column 3 of Table 2 (or better) to meet co-channel interference specifications into the affected TV channel.

CR WSD transmitters that do not fully satisfy the off-channel emission levels indicated in Table 2 would not have to be precluded from operating on the channel. Rather, their emissions (i.e., transmit power level) should be adjusted such that the limiting interference mechanism in the TV receiver is satisfied. Continuing with the previous example, a CR transmitter operating on channel 27 that only has an (N-1 adj. ch. transmitter) splatter level of -39 dBr/6 MHz, rather than the recommended -49 dBr/6 MHz, would not be able to present a -26 dB adjacent channel D/U ratio at the TV set without violating the specified co-channel interference emissions into the TV receiver. To maintain the +23 dB D/U ratio recommended for the desired (Ch. 26) DTV co-channel interference level, the CR would be limited to presenting -16 dB D/U ratio in upper adjacent channel 27. See Figure 4. Geo-location based CR transmit power computations are able to readily and accurately take these effects into account. The 10 dB difference in EIRP for this example would put the poorer (OOB) emissions CR unit at a disadvantage (either reduced range or reduced throughput) compared to the better (OOB) emissions CR unit, but it may result in a lower cost product. Ultimately, the market would decide which emissions ratios and corresponding EIRP levels provide a compelling product. For wide variety of short range applications, reduced transmit power levels may prove adequate. Note that a sensing-only WSD would have no direct way to compute required protection ratios and TV signal power levels, and would thus have to make very conservative assumptions based on sensed adjacent channel (and beyond) incumbent signal strengths. Like the general incumbent sensing problem above, these measured signal strength levels are subject to a wide variety of generally uncontrollable variables (e.g., antenna gain/height/polarization, building penetration, shadowing/fading, etc.).

In general, CR transmitters with greater spectral purity will, as indicated above, enjoy higher EIRP levels, and hence have higher performance levels for a given local TV signal strength. The ideal mask in Table 2 is, as already indicated, adequate to allow the highest EIRP levels at the CR transmitter, but relaxed off-channel ratios will prove more useful (and implementable) in practice. As long as sufficient transmit power level corrections are applied (whether in geo-location CR devices directly, or in sensing-only CR units with the appropriate margins), incumbent receiver protection can be assured.

Channel	D/U ratio (dB)	Off-channel emissions (dBr/6 MHz)
N	+23	--
N ± 1	-26	-49
N ± 2	-44	-67

N ± 3	-48	-71
N ± 4	-52	-75
N ± 5	-56	-79
N ± 6 - 13	-57	-80
N ± 14, 15	-50	-73

Table 2. *Ideal CR off-channel emissions vs. offset from a DTV channel.*

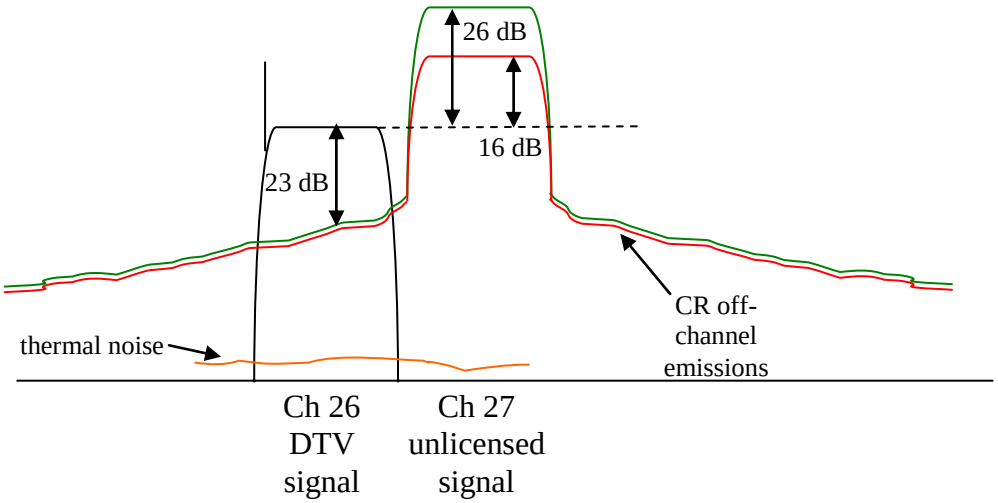

Figure 4. *Off-channel emissions of ch. 27 CR signal falling co-channel with ch. 26 DTV signal, as viewed at the TV receiver. The unlicensed radio with poorer emissions ratios (red) would be allowed less EIRP than the radio with better emission ratios (green), up to a limit defined by the recommended TV selectivity per Document A/74.*

In practice then, a CR WSD should have awareness of its off-channel (OOB) emissions profile for a given EIRP and adjust its EIRP accordingly to satisfy the limiting interference mechanism at the TV receiver. This method is more direct (and reliable) with the described geo-location database CR techniques above, while it is indirect (and less reliable) with sensing-only CR devices (since they would be required to locally measure adjacent channel incumbent signals and infer predictions about signal strengths at the TV receiver). For these reasons, it would be desirable to have a more controlled (restrictive) mask for sensing-only CR devices to ensure incumbent protection. Since the two classes of CR devices (i.e., geo-location and sensing-only) inherently have different application spaces and reliability levels, two classes of transmit masks are also desirable. (This approach is similar to high power and low power transmission masks in other bands.) Due to the value of the TV spectrum, a minimum off-channel performance level should be set to assure maximum utilization of the spectrum. Setting a minimum (base-line) performance level mask for each class of CR device also helps ensure stable and reliable TV-band system design and improved coexistence. CR WSD transmit masks that have already been proposed, or a mask that is already in use in the TV spectrum (and hence familiar to the incumbents) would be preferable.

To this end, Motorola recommends that minimum performance off-channel emissions for geo-location database-enabled CR units comply with the *simple LP-DTV* mask as described in 47

CFR § 74.794(a)(2)(i). This mask is defined by the attenuation characteristic relative to the average transmitted power

> At the channel edges, emissions must be attenuated no less than 46 dB. More than 6 MHz from the channel edges, emissions must be attenuated no less than 71 dB. At any frequency between 0 and 6 MHz from the channel edges, emissions must be attenuated no less than the value determined by the following formula:

$$A = 46 + \Delta f^{2} / 1.44$$

where the attenuation A is in dB relative to the total average transmit power per 500 kHz bandwidth (i.e., dBr/500 kHz), and the frequency Δf is 0 Hz at the near-edge of the adjacent TV channel and 6 MHz at the far-edge of the adjacent channel (see Appendix B). Note that the mask itself integrates to an adjacent channel attenuation level of about 39.5 dB relative to the average transmit power (i.e., the integral of the adjacent channel power spectral density would be -39.5 dB relative to the average transmitted power). If the actual CR emissions exactly followed this mask in the adjacent channel, the maximum D/U ratio in the adjacent channel as viewed at the TV set would be constrained to be less than -17 dB (as compared to a maximum of -26 or -28 dB) to satisfy co-channel emissions, which would limit CR performance in adjacent channels within protected contours. In practice the mask would more likely serve as a limit line where the CR transmitter splatter would be constrained at one point or another by an integrated splatter per 500 kHz band, but would otherwise fall below the mask. In such cases, the integrated adjacent channel emissions would be better than the -39.5 dB mask value, and provided the CR has knowledge of the integrated emissions levels, it could adjust its EIRP accordingly in typical geolocation database computations.

More than 6 MHz from the channel edge the attenuation is -71 dBr/500 kHz = -60 dBr/6 MHz, thus D/U ratios beyond the adjacent channel would be limited by the mask to -37 dB (-60 dBr + 23 dB C/I), whereas CR devices that follow the Table 2 ideal mask would be allowed to present from -44 dB to -57 dB D/U ratios at the TV set, a maximum difference of 20 dB. Again, some applications may satisfy some market demands without such high performance transmitters, and actual CR emissions may be better than the specified simple mask level. Note that low-power TV transmitter masks are fixed in frequency, while CR transmitter masks must generally be frequency agile, making their implementation more difficult. However, a minimum spectral mask should be enforced to maintain the integrity of the spectrum given its value. As indicated above, this portion of the mask would in practice serve as a limit line, and emissions integrated over a 6 MHz TV channel may be well below the suggested -60 dBr/6 MHz level. In such cases, the CR could increase its EIRP accordingly to again satisfy the limiting interference mechanism at the TV receiver.

For sensing-only based radios, the knowledge of the local TV signal strength is imperfect due to uncertainties in sensing antenna polarization and pattern, antenna height, frequency selective fading, and sensing receiver line-up gain. These limitations should be conservatively taken into consideration for sensing-only emissions masks and transmit power offset levels. Depending on how overall emissions levels are set based on the sensed fields, very conservative margins should be built into the mask.

The Commission has previously recommended Part 15.209(a) as an emissions floor limit (see Appendix B).[36] This is probably an adequate starting point for sensing-only portable CR devices. However, as with the geo-location enabled fixed access devices constrained by the simple LP-DTV mask, portable devices must have a rough awareness of the local signal strength available to nearby TV receivers (on adjacent channels and beyond), and their own off-channel emissions, and set their EIRP accordingly to ensure that their emissions satisfy the limiting interference mechanisms at the victim TV receiver as described above.

The Part 15.209(a) constraint for UHF is 200 μV/m at 3 m as measured with a CISPR-16 receiver using quasi-peak detection. The 6 dB bandwidth of the CISPR-16 receiver in the UHF band is 120 kHz. Assuming a 2nd-order synchronously-tuned bandpass filter, the noise bandwidth is approximately 94 kHz. The quasi-peak detector has 1 ms attack time and 550 ms decay time, followed by 100 ms time constant video filtering. For noise-like emissions over the bandwidth of the receiver (whether due to noise or a narrow slice of a random signal or its splatter), simulations indicate the quasi-peak detector with the given time constants reports peaks that are about 9.1 dB above the rms value. The detector stabilizes at a level where the charge injected through the 1 ms attack time constant by the occasional high peaks balances the charge bled off by the long 550 ms decay time constant. Thus to report 200 μV/m, the rms value of the E-field would have to be around 70 μV/m. This corresponds to an EIRP density of -58.3 dBm/94 kHz.

As with the simple LP-DTV mask presented above, an off-channel emission density that follows the 15.209(a) mask will have considerably worse performance than an emission that is only upper bounded by the mask. An EIRP density that remained at -58.3 dBm/94 kHz over the full channel bandwidth (to satisfy the 15.209 mask) of a DTV receiver would be at -40.7 dBm, which after ~ 40-45 dB of path loss for 10m separation (assuming 8 dBi net TV antenna gain), and perhaps some polarization mismatch, would present approximately a -81 dBm to -86 dBm interference level at the TV receiver. This level would violate 23 dB co-channel D/U ratios for signals weaker than -58 to -63 dBm (well inside the protected noise-limited contour), which would clearly be undesirable. Hence, the sensing-only CR must be well aware of its off-channel emissions levels to properly set its EIRP. Incumbent receivers will be affected in their co-channels, adjacent channels (and beyond) by CR system emissions. Minimum interference ranges greater than 10m would improve matters somewhat (e.g., 30m provides another 9.5 dB of path loss).

For a portable sensing-only CR unit EIRP of +10 dBm (as Motorola has recommended -see the *Sensing-only CR Device* section above), the Part 15.209(a) limit imposes a relative mask level per channel that is down about 51 dB relative to the average transmit power (see Appendix B). Again, EIRP must be set intelligently by the CR to ensure the limiting interference mechanism at the TV receiver is satisfied (i.e., TV co-channel interference protection ratios are met, at the expense CR device transmit power). The recommendation of 15.209(a) transmit masks are in line with the Commission's previous proposals, even though it has maximum allowed transmit power level implications.

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[36] See ET Docket No. 04-186, "*Unlicensed Operation in the TV Broadcast Bands*", 5/25/04, Appendix B.

5 Disabling Beacon Approaches

5.1 The Disabling Beacon Approach to Incumbent and Protected Systems

Motorola supports the use of a disabling beacon signal to protect incumbents. Note that a disabling control signal may be the only way to control interference issues in the field with sensing-only CR WSDs. A beacon signal can also serve to promote orderly co-existence (e.g., priority) among devices operating in the TVWS. Recent FCC OET laboratory and field tests performed on voluntarily submitted sensing devices designed for the detection of full power television ATSC signals indicate it is, at best, a challenging task to detect DTV signals at levels of -114 to -116 dBm and below.[37] Sensing and protecting Part 74 Subpart H devices operating at power levels of 250 mW and below is similarly challenging, even under ideal conditions.

Cross-polarization of the sensing antenna vs. broadcast television, additional building penetration losses, and reduced sense antenna height vs. the standard 9m television receiver antenna reference height add significantly to the sensing problem (see the Sensing-only CR Devices section above). TV broadcast signals are generally transmitted in the horizontally polarized plane, although some circular polarization is in use. Cross-polarized detection – the use of a vertical sense antenna to detect a horizontally polarized signal – potentially adds an additional 10-15 dB loss into the sensing link budget. Building penetration can easily add an additional 10 dB or more loss to the sensing link budget for a first barrier; multiple barriers, such as internal walls, can increase this amount substantially.[38] The level of additional building penetration attenuation can not be assumed; it is essentially incalculable in the general sense. These effects combine to make incumbent sensing (of any type) difficult.

As deployed, it is practically impossible to differentiate Part 74 Subpart H devices that require protection from other unlicensed signals that do not have regulatory rights of protection (owing to the fact that the wideband FM systems most commonly in use all appear alike spectrally and that no identifiable signature is broadcast by such devices). Augmenting the problem is the fact that some Part 74 devices, such as wireless microphone signals are, on a temporal basis, often un-modulated or lightly modulated by acoustical background noise, causing them to appear as discrete spectral tones. Under Motorola's proposed approach, two options for protecting licensed Part 74 wireless microphones exist; a populated, dynamic database, and a location-specific protective beacon. Both are feasible; the former requires CR WSDs to have access to a database while the latter requires the CR device to sense the presence of the beacon signal.

The use of a disabling beacon provides a means to directly protect Part 74 devices as well as any future use of TVWS by other systems that may require protection. It also provides the Commission with an absolute means to modify the power level of, or clear the spectrum of

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[37] See OET report FCC/OET 07-TR-1006, "*Initial Evaluation of the Performance of Prototype TV-Band White Space Devices*", 7/31/07, p. vi.

[38] See "*VHF/UHF Building Penetration Characteristics When Using Low Antenna Heights*", Turney, et al, Motorola, Inc., presented at IEEE DySpan 2007, April, 2007.

unlicensed devices, if desired. The disabling beacon concept has been addressed, in detail, by IEEE 802.22.1.[39]

The 802.22.1 disabling beacon conveys information to CR devices as well as all interested participants of TVWS spectrum. The information contains three discrete sub-parts: The actual beacon message, a signature of authenticity, and a certificate verifying the signature. Each section is explained, in detail, in the referenced draft. The message portion of the beacon (MSF1) contains the following information:

1) MAC address (unique device identifier)
2) Location (coordinates),
3) Protection radius,
4) Receiver height of the protected device,
5) Priority of the protected device,
6) Estimated time that protection is required,
7) Indoor / outdoor operation
8) 40 bit programmable field used for
    a. Sub-channel map (inter-beacon network)
    b. Channels in use, channel sub-grouping
    c. To be defined; user specific needs
9) Other information

The beacon is primarily a signaling system that informs WSDs that the channel is in use by licensed operations and must, therefore, be protected from interference. The beacon is inherently a one-way signal with respect to WSDs; WSDs may not control or communicate with devices operated under Part 74 Subpart H or other services.

The beacon is also configured to allow 2-way communications between multiple beacon devices on a cooperative basis, as described in IEEE 802.22.1. Multiple beacons may form a common network at a given location and reduce the number of active primary, protective beacons to one signal. Within the inter-beacon network, the beacons share information such as sub-channel mapping of a given television channel. This is useful in spectrum planning as well as reducing the amount of Part 74 spectrum required. One beacon transmitter is established as the primary protecting device. The primary beacon also sets the order in which alternate beaconing devices at a given location would replace the primary beacon in the event that the primary beacon ceases operation.

5.2 Detection of the Beacon

The beacon has been designed for detection utilizing various methods and levels of security.

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[39] See IEEE 802 Part 22.1: "*Enhanced Protection for Low-Power, Licensed Devices Operating in Television Broadcast Bands*", IEEE P802.22.1/D1; September, 2007.

The beacon itself has been proposed to occupy the same frequency as an ATSC / DTV pilot. In this fashion, a sensing receiver does not have to scan the channel for the presence of a beacon; it has a-priori knowledge of the location of a beacon signal within a television channel, thus substantially reducing beacon detection time. The beacon has been designed to be sensed and clear the channel within 2 seconds of elapsed time as cooperatively agreed upon by members of the broadcast and TVWS communities within IEEE 802.22.[40]

Questions have been raised over the security of the IEEE 802.22.1 beacon[41]. It has been suggested that the beacon would be utilized to, effectively, block all unlicensed use of the TVWS spectrum. Those making such statements have simply not followed the development process of the 802.22.1 beacon system; nor do they understand its operation in principle. The beacon has been designed such that various levels of verification can be performed by the unlicensed device based on transmitted information from the beacon. The unlicensed, CR sensing device can use as much of, or as little of, this information as the manufacturer sees fit to incorporate. In this way, a trust but verify scheme is utilized to insure authenticity of the beacon. This approach has been developed jointly in cooperation with the broadcasters, equipment manufacturers, potential TVWS service providers, and other interested parties under the guidance of IEEE 802.22.

To ensure maximum usefulness of any disabling beacon system, the beacon should be a controlled device. It should be licensed, or licensed by association, as is the case of most Part 74 operations. Although a unique signature and certificate are present in each beacon transmission, limiting use of these devices to authorized users increases the robustness of the system and reduces the burden of detection upon CR TVWS sensing devices. Security is provided via a public key approach; the keys are issued by a trusted source only after the legitimacy of use and license is established. While it is technically simple to generate an 8VSB signal, thus clearing the spectrum in a sensing-only environment, the beacon is extremely difficult to re-create owing to the level of security employed in the beacon message content.[42] The disabling beacon approach is far more secure and much less prone to false positive detection of incumbents (and other protected devices) than the general use of a sensing-only CR device scheme would yield in a fielded system.

The beacon can be identified by several means. One example is listed below. At the discretion of the beacon receiver designer, the following steps can be performed in the order listed. Once a given level of acceptance of the presence of the beacon is achieved, the remaining steps can be skipped. Each step offers an additional level of verification. The steps are:

1) A delay / multiply baud rate (feature) detector can sense the presence of the beacon, and requires approximately 520μs for detection. This is the fastest form of detection of the beacon. The baud rate of the beacon is chosen as a sub-multiple of the ATSC / DTV specification. Therefore, any detector of this type utilized for DTV sensing will also indicate the presence of the beacon.

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[40] See IEEE 802.22 Draft Standard, Version 0.3.7, September 17, 2007.

[41] Notice of Ex parte, filed 16 July, 2007, on behalf of the White Space Coalition, Edmond J Thomas, author, Filed by Harris, Wiltshire, Grannis.

[42] See "*Standard for Efficient Cryptography, SEC1: Elliptic Curve Cryptography*", Ver 1.0, Certicom Research, September, 2000; See also: http://www.secg.org/.

2) The sensing receiver can correlate to the pseudo-noise spreading sequence of the beacon signal. This provides falsing rates that have been simulated to occur less than once per day. This provides the first level of verification of the beacon signal. Correlation should require well under 2 ms.

3) Demodulation of the synchronization information in the "I" channel can be decoded as a next level of verification. This requires approximately 3.2 ms.

4) Once synchronization is established and the next frame start is determined, the beacon message can be received. From this, location and protection radius, as well as additional information, can be extracted. This provides the next tier of detection and verification. This step requires approximately 32 ms.

5) Next, the signature can be utilized to determine if the beacon is valid. The signature can be verified using a previously-received certificate, or over the internet. The certificate is active for several months, perhaps even a few years, so re-verification is seldom necessary. The certificate adds 42.5 ms to the transmission time; total time of MSF1 and MSF2 is approximately 75 ms.

6) Finally, the certificate can be received over the air and the signature can be verified without necessitating internet access. The certificate, MSF3, requires 33 octets or 27.5 ms for a total receive time of 103 ms.

The total time required to send a superframe (i.e., Beacon Message, Signature, and Certificate) is approximately 103 ms. This time was chosen such that it does not exceed about 60% of an 802.22 superframe. In this fashion, the 802.22 WRAN does not need to modify its sensing quiet time period; rather, it can capture the synchronization information and then wait until the non-synchronous 802.22.1 beacon is aligned within an 802.22 superframe. The 802.22 device then quiets for a portion of a single superframe and acquires the necessary portions of the 802.22.1 beacon message (at a minimum, the first MAC subframe that includes the license holder and deployment information). In this fashion, the 802.22.1 beacon device does not need to synchronize to an 802.22 device, which would violate rules governing bidirectional communications between CR TVWS and Part 74 devices.[43]

5.3 Protection of the Part 74 Device by CR WSDs When the Beacon is Received

Once the beacon is sensed to the satisfaction of the CR device and the channel is determined as requiring protection, the CR device could simply leave the channel. Since wireless microphones do not require protection over an entire market, a WSD, such as an 802.22 WRAN / CPE system could, alternatively, choose to protect the Part 74 device, yet continue to utilize the channel at reduced power or in sectors that will not affect the Part 74 device. To that end, the beacon information contained in the first MAC subframe MSF1 includes information necessary to determine power reduction levels or other methods to protect the Part 74 device. This includes geographic location, height of the Part 74 receiver (limited to less than 10 m or above 10m), whether the Part 74 device is utilized indoors or outdoors (a 10-15 dB building

[43] See 47 CFR 74.831, which states specific purposes of use, does not authorize non-Part 74 operators / users; 47 CFR 74.832, which states who can operate and control the Part 74 device; and 47 CFR 74.833(e) which states; "The user must have full control over the transmitting equipment during the period it is operated."

penetration factor can be associated with indoor operations when calculating path loss and protection ratios), the radius of protection required, and other factors that would aid in calculating the required protection to the Part 74 device. In this fashion, a WSD does not necessarily have to vacate the channel; it simply needs to protect the Part 74 device as deployed. The radius of protection parameter within the 802.22.1 MSF1 field can be utilized to clear larger physical areas, if necessary. As another example of the beacon's protection capability, consider the use of over-the-air (OTA) DTV receivers employed by CATV headend installations. Such installations may employ high gain OTA receive antennas to capture distant DTV stations for 'must-carry' service for thousands of customers. Though not its originally intended use, a disabling beacon could provide real-time interference protection to such installations by prohibiting CR use around a designated keep-out area centered on the installation. Thus, the beacon has numerous other applications other than protecting Part 74 devices.

Of particular interest to the Commission, there exists the capability to include eight levels of priority within the beacon signal. As proposed, Part 74 devices would automatically receive the highest level of priority and protection owing to the fact that they are currently considered as a child to the parent Part 73 television license. The remaining levels of protection could be utilized to either set up a method of tiered priority usage of TVWS, or to organize various users of TVWS that require protection. For example, in the case of itinerant, public safety (incident scene) use of TVWS could be given high priority, as it is in the public interest.

5.4 Considerations and Rules Changes Necessary to Deploy the Beacon

The beacon is intended to operate as a Part 74 device. It could also be certified for use by other services if appropriate rule changes are made. The link budget, FEC, modulation method, and other parameters have been chosen to optimize the link budget for reception out to approximately 15 km (by an outside antenna at 10m or higher). The beacon has been designed to operate without the need for a channel equalizer in the receiver, thus simplifying reception and detection methods (and circuit complexity within sensing receivers). Simulations have been performed using various models, including Channel Model B, as referenced in IEEE 802.22.

Rules that require modification or consideration:

1) The beacon has been designed to meet the link budget operating at a transmit power output (TPO) of 250 mW; the limit for UHF Part 74 operation. Less link budget occurs at VHF frequencies where the current rules allow for only 50 mW TPO. An increase (revising 47 CFR § 74.861-1) to 250 mW for VHF and UHF (TPO) for beacon operation would improve the link budget under adverse conditions at VHF. Note that this increase at VHF would not result in power exceeding the proposed 4 W (or 400 mW) EIRP limit for CR WSDs for any practical Part 74 VHF antenna.

2) The current Part 74 rules state that any device operating under Part 74 must have a carrier frequency that is fixed on a 25 kHz raster within the channel. To take advantage of the placement of the beacon at the DTV pilot frequency, an offset of approximately 9 kHz (DTV pilot at 309+ kHz from lower channel edge) is required. The beacon signal fits within a standard 200 kHz sub-channel even with this additional offset. Specifically, 47 CFR § 74.801C1 should continue to require 25 kHz integral multiples starting 25 kHz from the lower edge of the channel and add authorization to operate 309.4406 kHz above the lower edge of the channel.

3) A tighter RF emission mask, based on an ETSI-like mask, should be employed by the beacon to protect as much of the TV channel spectrum for Part 74 use, as well as the upper edge of the lower adjacent TV channel. The current Part 74 mask is not sufficient to do this. Such a mask has been proposed to IEEE 802.22.1. Specifically, 47 CFR § 74.861 should be modified to add, in addition to the current mask for non-beacon transmission, a tighter mask specific to the allowable emissions of the beacon.[44]

4) Clarifying language, specific to the operation of the disabling beacon, should also be added to 47 CFR § 74.861. This section deals with the transmission range and antenna height. While the rule states that excessive antenna heights allowing transmission of the signal beyond the required range are prohibited, exact heights are not given. It can be argued that the protective beacon would need to cover the interference range of the WSD; however, specifically authorizing operation consistent with protection of the Part 74 operation would eliminate any confusion over the intent of the rule and the requirement of the protective beacon.

5.5 Revised Location of Beacon Signal within the Television Channel

It is also possible to further reduce the impact the beacon has on the channel in use. IEEE 802.22.1 proposed placing the beacon at the DTV pilot frequency since there was assurance that all sensing receivers would pass this signal through any SAW filters and sample it with the A/D converter, where it would be available for digital demodulation. It was also thought; however, that if the beacon were placed at the channel edge, the WSD might not sense the beacon. If the Commission mandated placement of the beacon with a 100 kHz offset from the lower edge of the channel, and mandated detection of the beacon by CR devices that operate in TVWS, an additional 200 kHz sub-channel could be opened for use. This would be particularly useful for broadband devices which may also be developed for TVWS use (Part 74 or otherwise).

6 Other Issues

6.1 Licensed CR WSD Approaches

The TVWS proceeding offers the potential to implement cognitive sharing of spectrum between licensed primary users and unlicensed devices. It provides protection of licensed services, such as broadcast television, as well as secondarily licensed and/or quasi-licensed services such as Part 74 Auxiliary Broadcast Services (such as wireless microphones, video assist, and other related devices). Licenses issued under Part 74, such as those issued for Studio-to-Transmitter Aural and Video link (STL) and Remote Pick-up (RPU) services are linked in a Parent – Child basis within the FCC database; these are licenses that are associated with a primary, licensed entity. Likewise, some Part 74 devices, such as wireless microphones, can be licensed, but may also be operated through a method of linkage to the primary television broadcast license. This "*Licensed by Association*" concept has worked well for many years; the

[44] See P802.22.1-D2 Draft, released October 5, 2007, Section 6.8.3, Figure 12, Table 29.

broadcast industry maintains their own regional coordination forums, such as services provided by the Society of Broadcast Engineers (SBE) in many parts of the country.

The TVWS not only has the potential to fulfill a need for rural broadband services and in-home networking of consumer devices, it also can help meet the broadband needs of the land mobile community. TVWS devices provide the means to access additional spectrum on a temporary, itinerant basis for critical needs and services. Consider the spike in demand of spectrum that occurs at an incident scene in the public safety sector. While considerable spectrum has been allocated for such uses, there exist situations where quasi-protected use of TVWS for these services would be in the public interest. Broadband services for public safety now exist (at short ranges) in the 4.9 GHz band and will soon exist at 700 MHz band (for wide area networks). But, the limited amount of spectrum available for ad-hoc peer-to-peer broadband use in the 700 MHz band limits the amount of short-range, building-penetrating services that can be performed at an incident scene or manufacturing environment. These types of operations can be critical to homeland security, especially in cases of infrastructure destruction. But such future systems require propagation characteristics or localized available bandwidth/coverage that will not be sufficient in licensed spectrum. Nor is it feasible to utilize spectrum above 1 GHz for such operations when propagation characteristics such as building penetration become an issue. When such broadband services need only be used on a localized, short term basis, conventional licensed spectrum will not best meet the needs of such applications.

Cognitive use of TVWS can provide the necessary level of bandwidth, propagation and coverage required to meet the peak demand needs of the high data rate systems discussed above. Critical communications systems of this nature require protection from local interferers. While licensed services need to be continuously protected, such systems would benefit greatly from protection of interference from unlicensed non-critical services. Since the need for protection would be infrequent and localized, the beacon approach proposed to protect Part 74 devices would also be ideal to protect these systems as well.

Systems such as public safety and critical infrastructure and security deployments in the TVWS could also be protected in the same fashion as Part 74; the concept of “Licensed by Association” would properly address these requirements. In the case of Public Safety systems, the permanent VHF, UHF, or 800 MHz license held by the jurisdiction could be associated to the WSD. This could be performed by linking a device ID (e.g., MAC address), signature, and certificate of a PS WSD in the same fashion as Part 74 devices. The multiple protective tier concept supported by the beacon device would allow proper placement and priority of the system within the community of TVWS participants and users.

The TVWS rules will offer protection of television services, including those operating under Part 73 and Part 74 as primary allocations, but should also provide for forward looking revisions that might occur (e.g., through database updates and priority provisions in beacons). An approach for this would be to write rules in Part 15 such that unlicensed devices must provide protection on the basis of sensing of the protective beacon. A “Licensed by Association” clause could then be written for applicable service such as those service operating under the Part 90 rules. For example, the Part 15 rules that link protection of Part 73 and Part 74 devices could also reference protection of all authorized disabling beacon-protected devices. A subsequent rule in the Part 90 services would define the allowable use of TVWS for services such as PS and would authorize the use of the protective beacon (just as it must be authorized in Part 74).

Furthermore, restrictions could be placed on the deployment of the beacon when operated under Part 90 as appropriate. In this fashion, it is the beacon that is actually protected; the critical system obtains protection through its association to the beacon device.

Cognitive use of TVWS also offers enhanced interoperability at critical industrial and incident scenes. Devices need not be pre-programmed or programmed on site to offer inter-department or inter-agency communications. A primary beaconing device would establish and protect the usable channels at an incident scene. The inter-beacon network concept devised by 802.22.1 could be utilized to further coordinate use of this additional spectrum. While Part 15 TVWS use will not guarantee the level of interference protection provided by directly-licensed channels and allocations, it can provide the necessary spectrum needed to handle the additional, secondary needs, particularly for additional ad-hoc (e.g., peer-to-peer) broadband wireless data services.

6.2 Other General CR Device Characteristics

6.2.1 CR Device Upgradeability

The mechanisms being proposed for CR units which will operate in the TVWS spectrum will continue to advance as the technology is investigated further. As more CR units and other communications systems occupy the band, new mechanisms may be needed to accommodate operational situations that have yet to be considered. Therefore, there is a need for flexibility and upgradeability in the WSDs which will be deployed in this band. One good example of this required flexibility would be for implementing new types of incumbent detection algorithms (e.g., as needed for the introduction of new services, similar to the case of ATSC modulation being introduced). Manufacturers that support such flexibility would be able to enjoy longer equipment lifetimes. Motorola has extensive experience in implementing software upgradeable radios (e.g., in high volume cellular phones). The software update mechanisms employed are both secure and practical. Motorola recommends that all WSDs support software updates. Many CR WSD units are expected to be linked (directly or indirectly) to the internet, so there exists a convenient and well-accepted mechanism for distributing software updates.

6.2.2 *CR Device Coexistence*

As mentioned above, the beacon approach promotes a level of orderly coexistence through a priority structure. Geo-location database approaches can also promote orderly coexistence among many different services (e.g., TV broadcasters, LMR/CMR operations, wireless microphones, and even other TVWS systems) on less of a real-time basis. It is important to note that other TVWS systems can utilize the incumbent database approach to reserve operating spectrum (especially for fixed access cases, such as IEEE 802.22) as long as operational use / fairness rules are established. For example, maximum usage time duration on a channel may be limited, and the maximum number of channels utilized by a particular service provider should be limited (e.g., to two channels) in a given geographic area. Furthermore, rules preventing “camping out” on unused channels in order to reserve or hold them for future use should be prohibited. In a similar manner, explicitly imitating licensed services (e.g., a DTV transmission) for the purposes of barring other (equal priority) users from the channel should be prohibited.

Common methods exist for the sharing of communications channels (such as the popular 802.11 carrier sense multiple access/collision avoidance protocol). One of the main drawbacks to such systems is their relatively low spectral efficiency (after accounting for all of the various protocol overhead amounts). Other systems, such as scheduled OFDMA/TDMA systems generally have higher spectral efficiency, but are less open to dissimilar off-network users. Note that regardless of system type, the use of incumbent databases may allow CR units to register their approximate operating locations and times, which could be augmented with modulation/access method information to ease the coexistence problem. (Geo-location databases offer the opportunity for many exciting new possibilities such as this.) Wireless beacon approaches mentioned above could also be augmented with such information, to promote real-time system coexistence.

As with any communication system, in the interest of minimizing overall system interference levels, it is expected that communications links will be established with the minimum power level required to reasonably maintain that link (for the required data rates). This implies mandatory power control in CR devices over some minimum range (e.g., 40dB) to be useful. Note that it is anticipated that geo-location database-enabled CR units will possess this level of power control anyway, since allowed transmit power levels will vary versus geographic location.

7 Conclusions

Further detail has been presented on a variety of WSD operation requirements. As previously stated, it is in all TVWS participants' interest to adequately protect incumbent services in the TV bands. Motorola has proposed a multi-tiered approach to protecting licensed incumbents. Motorola strongly encourages the use of geo-location database techniques, in combination with spectral sensing and wireless beacons to protect incumbents and provide unprecedented control over fielded WSDs. The 3-level approach detailed above offers the highest level of protection and adaptability to unexpected or changing conditions in the field. For sensing-only CR devices, the use of limited transmit power levels and disabling beacons is recommended in order to control interference issues in the field.

Two general classes of CR WSDs are proposed, a summary list of recommendations is provided below for each class of device:

Class A: Higher-powered geo-location enabled CR WSDs, suitable for high power applications such as rural broadband deployment; and

Class B: Low-power sensing-only CR WSDs, suitable for consumer use in the home.

7.1 Summary List of WSD Recommendations:

Class A (geo-location-enabled WSD):

- Incorporates location determining means with the required accuracy (i.e., 300m, with 95% confidence) and allows highly conservative location uncertainty techniques to be utilized.
- Utilizes Commission CDBS-like incumbent database system, Commission recommended propagation models (i.e., F(50,90), F(50,50), F(90,90), two-ray), and appropriate (D/U) protection ratios for modeling TV transmitters and receivers, as described in the May ’04 NPRM. Also allows the use of simplified two-ray CR signal propagation models.
- Utilizes mirrored incumbent databases (likely maintained by a 3rd party), which allows authorities and incumbents to readily address interference issues and new services in the field.
- Allows fixed-portable, portable, and tethered portable geo-location enabled device operation at power levels up to 36 dBm.
- Incorporates spectral sensing capability to further characterize channels.
- Incorporates IEEE 802.22.1 disabling beacon techniques.
- Utilizes simple LP-DTV transmit spectral mask, with appropriate adjacent channel emissions modeling in setting allowed transmit power levels.

Class B (sensing-only WSD):

- Portable (in-home) devices limited to 10 dBm transmit power levels due to direct pick-up issues and uncertainty about sensing field performance.
- Meets an overall required incumbent detection level (e.g., >95%), based on a defined incumbent detection threshold (e.g., -116 dBm for DTV), sensing signal reliability (l,t) level, probability of sensor detection level, and maximum allowed transmit power level.
- Requires rigorous sensing performance testing, including faded channel.
- Utilizes 15.209 transmit spectral mask, and appropriately adjust transmit power levels based on out-of-band emissions.
- Incorporates IEEE 802.22.1 disabling beacon techniques to allow device control in the field (essentially only method available).

8 Abbreviations

AP	Access Point
ATSC	Advanced Television Systems Committee
ATV	Analog TV
CATV	Cable Television
CDBS	Consolidated DataBase System
CMR	Commercial Mobile Radio
CR	Cognitive Radio, essentially a TVWS device (or WSD)
dBi	Decibels Isotropic
dBm	Decibels relative to 1 mW power
dBr	dB relative to the average transmitted power
dBu	Decibels relative to 1 microvolt/m
DT	Full Power DTV station (FCC service code)
DTV	Digital TV
D/U	Ratio of desired signal strength to undesired signal strength
EIRP	Equivalent Isotropically Radiated Power
ERP	Effective Radiated Power
F(l,t)	Field strength exceeded at l% of the potential receiver locations t% of the time.
FCC	Federal Communications Commission
HAAT	Height Above Average Terrain
IEEE	Institute of Electrical and Electronics Engineers
LD	Low-power DTV station (FCC service code)
LMR	Land Mobile Radio
LP-DTV	Low Power Digital Television
NLC	Noise Limited Contour
OET	Office of Engineering and Technology (of the FCC)
OTA	Over-the-Air
PS	Public Safety
RCAGL	Radiating Center Above Ground Level
TPO	Transmit power output
TX	Transmit
TX	also, FCC service code for TV Translators

TV	Television
TVWS	TV White Space
UHF	Ultra High Frequency
VHF	Very High Frequency
WLAN	Wireless Local Area Network
WSD	White Space Device

Appendix A – CR WSD System Propagation Models

There are a wide variety of propagation models available for predicting received signal strengths. The most widely accepted models for TV signals involve the application of the FCC's F(50,t) curves, where t is the desired time reliability. Such calculators are available online, and require standard TV transmitter parameters (e.g., ERP, HAAT, protected contour levels, etc.).[45] The Commission has proposed the use of F(50,10) curves for modeling co-channel interference effects from WSDs, and the use of F(50,50) curves for modeling adjacent channel interference effects from WSDs. Typically, these models are not available for transmitter distances less than 1.5 km (where the propagation is assumed to be square-law), and for transmitter antenna heights of less than 30m (HAAT). Thus, height-corrected models (such as the Hata models referenced above) must be utilized.

A computational simpler, but realistic method of computing WSD (CR) signal propagation utilizes two ray propagation models. This type of model breaks from square-law propagation to 4th law propagation loss at a defined break-point. (It is essentially a piece-wise linear model for path loss on a log scale). The break-point is frequency dependent, as well as transmitter and receiver height dependent. A general model for the break-point is given below:

$$BP(m) = [\ (K * H_{TX} * H_{RX}) / \lambda\ ]$$

where BP is the 2nd-law to 4th-law break-point in meters, K is a predefined constant, λ is the wavelength (in m), H_{TX} and H_{RX} are the heights of the transmit and receive antennas (respectively). This model allows computationally simple prediction of signal strength dependent on antenna heights and frequency. It is applicable to computing CR signal strength at realistic antenna heights (e.g., 2m transmit and 9m receive) in order to compute interference effects on incumbent receivers. The model also matches field propagation data for suburban areas well. A diagram comparing F(50,10), F(50,50) and the above two-ray models (for K=2 and K=8) is shown below:

[45] See the http://www.fcc.gov/mb/audio/bickel/curves.html website.

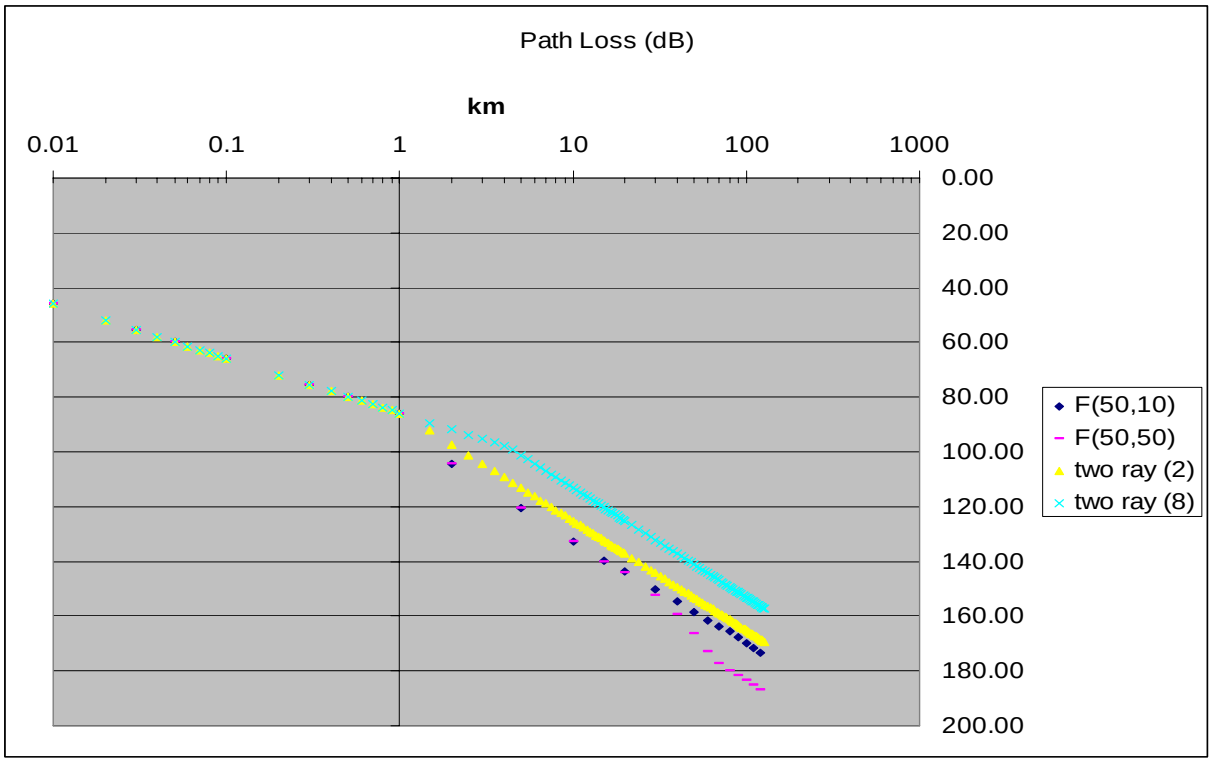

Figure A1. *Comparison of different FCC propagation models and two-ray propagation models*

As can be seen, the two-ray model with K=2 (with H_{TX}=30m and H_{RX}=9m) closely matches the F(50,10) model (with TX HAAT=30m and 9m receive antenna height assumed). In fact, the model predicts roughly 6 dB less path loss than the F(50,10) model (after the break-point), which means that it is conservative with respect to incumbent protection levels (since it will model CR signals as appearing stronger than the F(50,10) model). The model is also assured to be essentially square law within the defined 10m interference radius (for all TVWS frequencies), which is also somewhat conservative.

It is suggested that this model be utilized in computing CR signal strengths and their corresponding interference effects. The model is computationally simple, and provides a good estimate of F(50,10) propagation. It also does not require complicated (e.g., Longley-Rice) model height corrections. Effective control of the two-ray model can be achieved by controlling the break-point constant value (K). Higher values of K push the 4th law propagation break-point further out in distance (which essentially amounts to conservative free-space propagation modeling over larger distances). Models with lower values of K (e.g., K=0.87) can be shown to match the F(50,10) curves more closely for a variety of transmit antenna heights (>30m), however, they are deemed to be less conservative.

Appendix B – WSD Spectral Masks

The proposed WSD spectral masks are as follows:

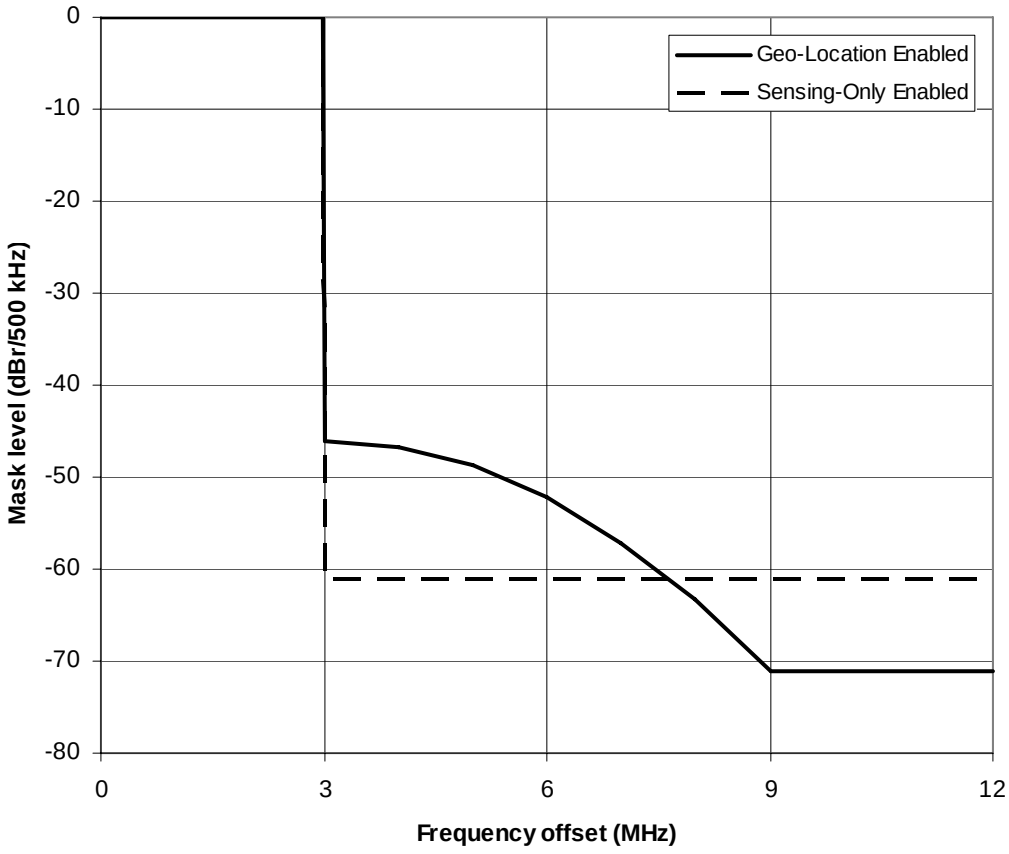

Figure B1. *Proposed WSD transmit spectral masks (Class A and Class B).*

The geo-location enabled CR device mask is based on the well-known simple LP-DTV mask, and the sensing-only CR device mask is based on the Commission's proposed 15.209(a) emissions limits (with 10 dBm transmit power assumed). Frequency offset is shown relative to the center of the desired active channel. Both masks will require CR device power control to assure that OOB emissions do not exceed TV co-channel interference limits. (This calculation can be performed directly in geo-location enabled CR units, while it must be inferred from sensing measurements in sensing-only CR units.)