

Geo-location Database Techniques for Incumbent Protection in the TV White Space

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Abstract— The opening of the television bands in the United States presents an exciting opportunity for secondary spectrum utilization. Protecting licensed broadcast television viewers from harmful interference due to secondary spectrum usage is critical to the successful deployment of TV white space devices. A wide variety of secondary system operating scenarios must be considered in any potential interference analysis, as described below. Several different types of licensed television transmitters currently exist in the TV bands, along with secondary licensed services, such as wireless microphones. All licensed services must be adequately protected from harmful interference, which can readily and reliably be achieved with the described geo-location database methods. Specific implementation details of geo-location databases are discussed, including several complexity reduction techniques. Geo-location database techniques are also shown to more efficiently utilize available spectrum than other spectrum access techniques.

Index Terms—Geo-location database, Incumbent Protection, TV White Space (TVWS), White Space Device (WSD).

I. INTRODUCTION

Numerous methods exist for protecting incumbent systems, ranging from sensing-only methods to geo-location database techniques. The reliability of these methods is of paramount concern. Sensing-only incumbent detection methods face challenging performance and design issues, as verified by recent FCC testing of experimental TV white space devices [1]. Conversely, geo-location database techniques rely on known information about the bands, including the exact types of incumbent services present and their specific protection requirements. Sensing-only devices do not possess the same level of knowledge about the bands.

In this paper we describe how geo-location databases can be utilized, along with specific operating requirements to determine not only if a TV channel is available for secondary usage at a particular geographical location, but also to determine a maximum allowed safe transmit power level (per channel) at the operating location to avoid causing interference to licensed incumbents. This process relies on computations that take into account proximity to licensed transmitters and

receivers, specific transmitter types (e.g., full-power digital TV, low-power analog TV, low-power digital TV, etc.), and specific receiver interference protection requirements (e.g., on the co-channel, adjacent channel, etc.) to avoid harmful interference. The specific propagation models that were used to compute both the predicted licensed signal levels and interfering signal levels are described. Location uncertainty concepts are also discussed.

Generally, system operating requirements and protection requirements are specified by regulatory bodies such as the FCC in the U.S. The FCC has already put forth proposed rules for secondary unlicensed use of the TV bands in the United States [2]. A detailed discussion of this proposal is presented below. The implementation costs of the geo-location database techniques are also examined, and methods for reducing computational complexity are presented. A fully functional embedded implementation of geo-location database techniques will also be briefly discussed. Using the described techniques, detailed maps of spectral availability can be generated for the TV bands anywhere in the United States.

The efficient utilization of available spectrum is also an important concern. In this paper, the differences in spectrum utilization between sensing-only and geo-location enabled devices are examined. Specifically, the paper will show that sensing-only devices do not generally utilize spectrum as efficiently as geo-location enabled devices, due to the large margins in incumbent detection thresholds that must be built into sensing-only devices. Geo-location enabled devices have knowledge of the specific interference protection requirements of each licensed incumbent, which allows varying levels of protection to be applied (often for signal types that have the same spectral signature, and would be indistinguishable for sensing-only devices), maximizing utilization of the spectrum.

Finally, the paper will describe how geo-location databases allow important dynamic updating techniques to be utilized after the transceiver has been deployed. In this manner, specific interference protection requirements can be dynamically altered to address system interference issues long after devices are fielded. These techniques allow specific interference problems to be readily corrected, providing an additional safety measure to regulators concerned about interference issues after device deployment.

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II. INCUMBENT SYSTEM PROTECTION REQUIREMENTS

A. Types of Incumbents

There are several types of licensed incumbents present in the TV bands in the U.S. today. This includes a variety of different types of analog (NTSC) and digital (ATSC) broadcast operations. Currently, both full power analog and digital stations, as well as several types of analog and digital low power stations operate in the TV bands. The full power analog broadcast stations will be going off the air after February 17th of 2009 by FCC order, though numerous low power analog TV (LPTV) stations are expected to remain in service after that date, and will be entitled to protection.

Detailed information about U.S. TV band allocations can be found in the FCC’s Consolidated DataBase System (CDBS), which can be accessed via the FCC TV Query website [3]. The FCC assigns two character service codes to these operations to specify the service class, which in turn specifies the protection requirements for the stations. Some examples of service codes include ‘TV’ for full power analog stations, ‘DT’ for full power DTV stations, ‘LD’ for low power digital stations, and ‘TX’ for low power analog translator stations. Generally, full power stations are afforded higher levels of protection than their low-power counterparts, as described in the next section. Other service codes are also utilized, including the ‘LM’ code to indicate land mobile radio (LMR) operations that are present in the T-band (UHF channels 14-20). Secondary licensed wireless microphone operations may also take place in the TV bands under FCC Part 74 rules [4]. Such operations can be protected through geo-location database techniques as well as through IEEE 802.22.1 disabling beacon techniques.

B. Protected Service Areas

Each type of licensed incumbent system described above has specific interference protection requirements. Each TV station has a commonly regulated protected service area that is determined by its Grade B Contour for analog broadcast operations or its Noise Limited Contour (NLC) for digital broadcast operations. Generally, it is assumed that operation of TV white space devices (WSDs) is not allowed co-channel within these pre-defined service areas. TV station service contours are determined by a variety of CDBS station parameters, including effective radiated power (ERP), antenna pattern, antenna height above average terrain (HAAT), operating band/channel, and service type. The FCC has long defined the protected service contour levels in terms of a minimum TV signal E-field strength at a 9m high outdoor receiving antenna for various station types. These levels are presented in Table I, as proposed by the FCC [2].

These levels along with the specific transmitter parameters effectively define a given station’s protected service area once a TV signal propagation model is established. The FCC has long supported F-curves for TV signal propagation modeling [5]. The F-curve models are TV-band specific, and can be applied to both analog and digital broadcast signals. The F-

TABLE I
PROTECTED SERVICE CONTOUR LEVELS

| Type of TV station | Band/Channel | Protected Contour E-field Level (dBu) |
|-----------------------|-----------------|---------------------------------------|
| Full Power Analog TV | Low VHF (2-6) | 47 |
| | High VHF (7-13) | 56 |
| | UHF (14-69) | 64 |
| Low Power Analog TV | Low VHF (2-6) | 62 |
| | High VHF (7-13) | 68 |
| | UHF (14-69) | 74 |
| Full Power Digital TV | Low VHF (2-6) | 28 |
| | High VHF (7-13) | 36 |
| | UHF (14-51) | 41 |
| Low Power Digital TV | Low VHF (2-6) | 43 |
| | High VHF (7-13) | 48 |
| | UHF (14-51) | 51 |

curves are statistical propagation models derived from actual measurements, and are fully specified by operating band, ERP, HAAT, location (l) and time (t) percentage reliability requirements (in the format of $F(l,t)$). Higher location and time reliability levels will generally result in lower predicted E-field levels using these models. An example of the F(50,90) curve for the UHF band is shown in Figure 1 below. The FCC has specified the use of F(50,50) curves when computing analog Grade B service contour levels, and F(50,90) curves when computing digital NLC levels. Note that digital (ATSC) modulations are afforded a higher time reliability since service degrades much more abruptly (at the signal Threshold of Visibility, or TOV) compared to analog (NTSC) modulation.

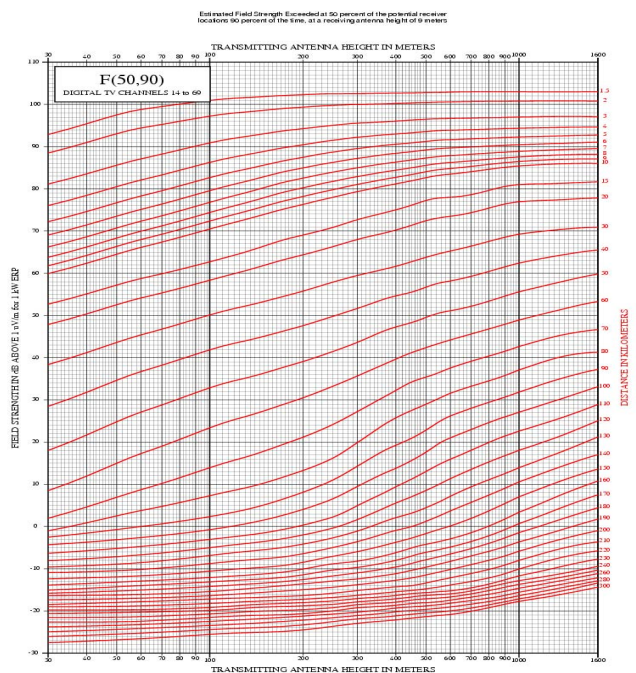


Fig. 1. FCC F(50,90) UHF signal propagation curve.

TABLE II
REQUIRED INTERFERENCE PROTECTION RATIOS

| Type of service | Channel Offset | Interference Protection D/U Ratio (dB) |
|-----------------|----------------|--|
| Analog TV | Lower Adjacent | -14 |
| | Co-channel | 34 |
| | Upper Adjacent | -17 |
| Digital TV | Lower Adjacent | -28 |
| | Co-channel | 23 |
| | Upper Adjacent | -26 |

Note that each station's ERP is weighted by the antenna pattern of the transmitter in the particular radial direction (or azimuth) of interest from the transmitter location, and that the HAAT values may also be specified in the particular radial direction of interest (e.g., typically specified in 1 degree increments based on terrain data). TV transmitter antenna pattern relative field strength data is typically stored in the CDBS in 10 degree increments. Radial HAAT data can be calculated from detailed terrain databases for each particular signal direction (given the location of the transmitter) and the resulting values can be stored for each incumbent transmitter. Radial HAAT data becomes more important for computing incumbent service areas in mountainous regions (e.g., parts of the western U.S.). This approach has the added advantage that the actual propagation calculations (which may be performed locally in the WSD using F-curve methods) do not have to store detailed terrain databases (which can amount to several gigabytes of information), but can still incorporate terrain effects into protected service contour calculations. This approach significantly limits geo-location database implementation complexity.

As currently proposed [2], LMR sites (which are often utilized for mission critical two-way public safety mobile radio communications in the T-band) have special protection requirements, requiring keep-out zones of 134 km and 131 km around the geographic center of operations on both the co- and adjacent channels (respectively). Note that only 13 major cities in the U.S. have T-band LMR channel allocations, and these locations are also indicated in the CDBS.

C. Receiver Protection Requirements

For any type of incumbent system (analog or digital), receiver performance levels are an important part of overall system protection. Once again, the FCC has long had to take such factors into account in the licensed TV band channel allocation process. In particular [6] describes various receiver system parameter assumptions for evaluating TV coverage and interference levels. Many of these same interference protection requirements have been proposed by the FCC for WSDs [2]. Table II below describes common interference protection ratios that must be applied for both digital and analog TV receivers to avoid interference. The ratios are typically specified in terms of desired-to-undesired (D/U) signal levels. These ratios take into account the effects of full power TV transmitter splatter (or Out of Band Emissions, OOB).

In addition, there have been numerous studies of DTV receiver performance levels [7]-[9] in the presence of interference. Note that the ATSC A/74 specification [10] also recommends receiver interference tolerance levels, though the FCC-proposed levels for TV white space operation are often more conservative with respect to potential interference. For example, ATSC A/74 recommends -33 dB DTV adjacent channel receiver D/U performance levels, though this measure assumes negligible transmitter splatter. FCC OET lab measurements of various DTV receivers also showed significantly higher adjacent channel interference tolerance (e.g., of approximately -40 dB D/U levels) for typical DTV receivers [8]. Also note that these interference levels assume continuous interfering modulations, and that bursted modulations may cause less noticeable interference to incumbent systems [11]. Interference protection requirements for channels further removed (e.g., alternate, or $N\pm 2$) may also be readily incorporated into WSD interference protection schemes.

The above required interference protection ratios need to be met for all WSD operation scenarios, including for both sensing-only WSDs and geo-location enabled WSDs. These requirements help determine what WSD transmit power levels are permissible to avoid causing interference to incumbent systems.

Generally, sensing-only WSDs must not only determine if an incumbent is present by detecting incumbent signals over a specified threshold (such as the -116 dBm level for DTV signal detection, as proposed by IEEE 802.22 [12]), but they must also adjust their maximum transmit power levels downward based on sensed adjacent channel incumbent signal levels. Examples of this power control method for sensing-only WSDs are given in [13].

Geo-location database enabled WSDs, on the other hand, do not need to sense for the presence of incumbents, since they already know the geographic location of incumbents (in addition to their own location, which can be determined through a variety of means, e.g., GPS), and can compute the protected service contours for each station. Using similar techniques, geo-location enabled units can also compute signal strengths of adjacent channel incumbents (using highly conservative assumptions) in order to adjust the unit's transmit

power to meet the required incumbent interference protection ratios. These methods are described in detail in the next section.

III. DETAILED GEO-LOCATION DATABASE WSD OPERATION

As proposed by the FCC, all WSDs must avoid co-channel operation within a station's protected service contour. However, WSDs may operate outside of protected service contours, as long as they can meet *all of the required interference protection ratios* described in Table II at the *nearest edge* of each station's service contour. In this case, the TV signal strength at the edge of the contour is defined by Table I, and the WSD signal strength must be computed at the nearest contour edge of each station. Note that the direct path to the TV transmitter may not be the path to the nearest contour edge, as shown in Fig. 2.

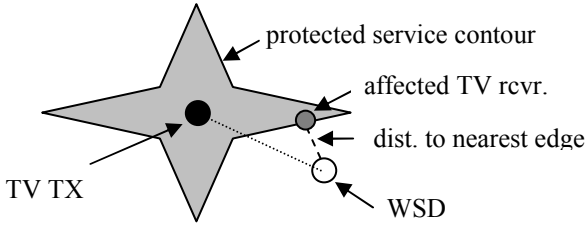


Figure 2. Nearest contour edge modeling

At the nearest contour edge location, both the co-channel and adjacent channel interference protection requirements must be met for the affected incumbent receiver. For example, for reception of a full power UHF DTV station at the edge of its service contour, all co-channel interference must be 23 dB below 41 dBuV/m (by convention, dBu), or no more than 18 dBu. The adjacent channel interference must be no more than 28 dB above the 41 dBu level (for lower-adjacent channel WSD operation), or 69 dBu. Note that these levels are calculated at the affected TV receiver antenna, and do not typically assume any receive antenna pattern discrimination (which could amount to as much as an additional 14 dB of WSD interfering signal reduction in the UHF band) [6]. Furthermore, note that alternate channel interference protection may also be enforced, though this level of protection has not been currently proposed by the FCC. The above maximum allowable interference levels effectively limit WSD transmit power levels (i.e., WSD transmit power level must be reduced to ensure that the specified levels are not exceeded). The specified interference protection ratios assume that the WSD interference is continuous and wideband (e.g., 6 MHz) in nature, which also may be pessimistic assumptions.

Note that while not specifically proposed by FCC, the authors support individually modeling both on-channel WSD emissions as well as off-channel WSD emissions (i.e., WSD transmitter splatter or OOB). In this manner, a WSD operated on an adjacent channel to a TV station causes

adjacent channel interference based directly on the WSD's transmit power level, but it also causes co-channel interference based on the WSD transmit power level and relative splatter [14]. For example, if the WSD's integrated adjacent channel splatter is -39 dB/6 MHz (as it would be if the WSD met the *simple LP-DTV* transmit spectral mask), and it was transmitting at a 20 dBm power level, then its effective adjacent channel emissions would be at a -19 dBm level over the 6 MHz adjacent channel. Both 'signals' can be propagated to the nearest affected incumbent receiver, and all appropriate (e.g., co- and adjacent channel) interference protection ratios should be met at that point. Mathematically, the maximum allowable WSD E-field at the affected incumbent receiver antenna for a WSD operating on the incumbent's adjacent channel would be

$$E_{WSD_{max}} = \min\{(E_{TV} - (D/U)_{cc} - WSD_{acs}), (E_{TV} - (D/U)_{ac})\} \quad (1)$$

where E_{TV} is the E-field strength of the affected adjacent channel TV signal at the incumbent receiver antenna, $(D/U)_{cc}$ and $(D/U)_{ac}$ are the maximum tolerable co- and adjacent channel interference protection ratios for the affected service, and WSD_{acs} is the relative adjacent channel splatter (in dB/6MHz) for the WSD transmitter. Note that the maximum allowable WSD transmit power can be computed from this quantity based on the propagation distance to the nearest affected receiver and propagation frequency (as described below).

In this manner, the actual WSD transmit spectral mask levels become less important for interference-free operation, since the WSDs are modeled at whatever interference levels are present (i.e., a WSD with poor splatter performance will be penalized with lower maximum allowable transmit power levels).

The FCC has proposed utilizing F(50,10) propagation curves for modeling WSD co-channel interference levels, and F(50,50) curves for modeling adjacent channel interference levels. Note that F(50,10) curves will generally predict higher allowable WSD signal strengths than F(50,50) curves. However, F(50,10) curves are generally ill-defined for propagation distances of less than 15 km, and both F(50,50) and F(50,10) curves are undefined for transmit antenna heights below 30m (which includes many WSD use cases). Therefore, the authors suggest the use of a computationally simple but relatively accurate two-ray propagation model with a break-point between square-law and fourth law propagation defined at:

$$d_{BP} = K H_{TX} H_{RX} / \lambda \quad (2)$$

where d_{BP} is the 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 WSD transmit and incumbent receive antennas (respectively). Typically, K ranges from between 0.5 to 8, with typical values being around 2.0. Higher values of K are

generally more conservative in terms of estimating WSD induced interference. A plot comparing the path loss of the above propagation models is presented below in Fig. 3. As can be seen, the simplified two-ray model with $K=2$ (with $H_{TX}=30\text{m}$ and $H_{RX}=9\text{m}$) closely matches the F(50,10) propagation model (with a TX antenna HAAT of 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).

Using the above techniques, a maximum allowable WSD EIRP level can be computed as follows:

$$EIRP_{\text{WSD}} = \frac{4\pi d^4}{d_{BP}^2} \frac{E_{\text{WSD max}}^2}{\eta}. \quad (3)$$

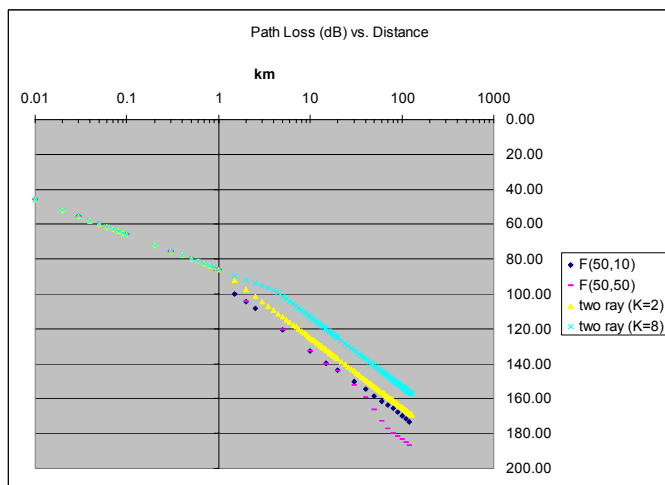


Fig. 3. Comparison of WSD propagation models

Finally, the FCC has proposed allowing WSDs to operate within a service contour on an adjacent channel (i.e., the WSD may transmit on an incumbent's adjacent channel while within its protected service contour). This operation is subject to tight constraints as currently proposed. The main constraint is that all required interference protection ratios (as in Table II) must be met for all incumbent receivers 10m or greater away from the WSD location, since devices within 10m are assumed to be under the WSD operator's control (and can tolerate operator self-induced interference).

Furthermore, standard F(50,50) and F(50,90) propagation models can no longer be employed for modeling TV signal strength, and highly conservative F(90,90) incumbent signal propagation models must be employed. First, note that F(90,90) models typically produce incumbent signal level estimates that are about 12 dB below F(50,90) models, which in turn tends to reduce the maximum allowable WSD transmit power levels [13]. Second, according to the DTV receiver performance levels measured in [8] above, and the described

individual WSD interference modeling techniques described in (1) above, the FCC proposed interference protection ratios of -26/-28 dB (upper and lower adjacent channel for DTV, respectively) are deemed to be about 12-14 dB conservative in relation to the -40 dB average adjacent channel D/U ratios measured in the OET report. Note that these measured levels assumed negligible transmitter splatter, which is a valid assumption for the described individual WSD interference modeling techniques (though they would not be valid if only WSD on-channel interference effects were modeled). So, overall, the FCC proposed rules for WSD operation within adjacent channel contours may be up to about 26 dB conservative when considering both of the above effects.

Furthermore, the FCC-proposed 23 dB co-channel interference protection ratio for DTV assumes the weakest possible receivable (worst-case) incumbent signal strength. Under the proposed WSD operating rules, incumbent signal levels will be much higher than these minimum signal levels when operating inside of adjacent channel contours, thus the actual tolerable DTV co-channel interference tolerance ratio may be closer to 16 dB than 23 dB, since thermal noise components affecting TV reception are negligibly low inside of protected service contours where adjacent channel WSD operation is feasible (i.e., at locations relatively close to the TV transmitters).

Note that having some level of protection margin is desirable, since the WSD employs propagation modeling to predict incumbent signal strength within service contours, and actual signal levels that are lower than these predictions are at a higher risk of being subject to WSD interference. Thus, with the FCC proposed geo-location enabled WSD operating rules described above, very large errors can be tolerated in incumbent signal level prediction without causing interference.

IV. GEO-LOCATION DATABASE RESULTS

A. Sample Geo-location Database Results

Some plots of maximum allowable WSD transmit power (EIRP) levels computed using the above described techniques for the Chicago, IL area are shown in Figs. 4 and 5. The plots assume that a 36 dBm maximum WSD EIRP level is allowed, current FCC CDBS TV band channel allocations, a maximum 10m interference radius, and an omni-directional WSD antenna is employed. The two plots cover roughly a 100 km x 100 km area, and are referenced by latitude and longitude coordinates.

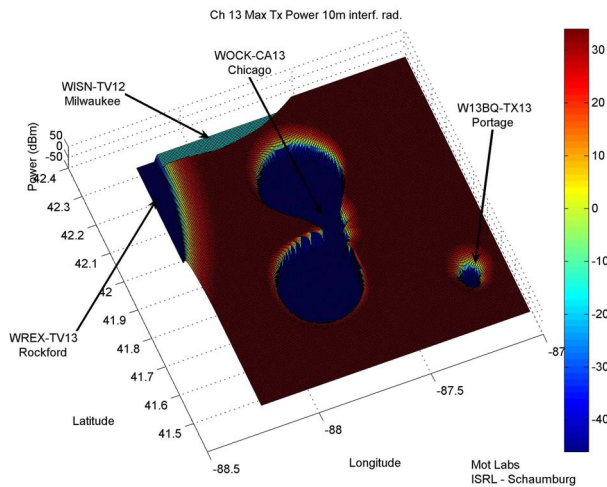


Fig. 4. Geo-location database plot of maximum allowed WSD transmit power level (EIRP) for Ch. 13 in the Chicago area.

The dark blue color indicates the protected service contour areas of licensed incumbent TV stations, where WSD operation on that channel would not be possible. In general, the effects from distant stations must be considered when generating geo-location databases, since some stations may have very large (e.g., >80km) coverage radii. A good rule of thumb is to include incumbents from at least an additional 120 km outside of the examined geo-location database region. The shapes of the contours are directly related to the station antenna pattern data. The dark red color indicates areas where WSD operation is possible at full power (36 dBm) levels. The green and yellow colors indicate areas where WSD operation is possible (inside of incumbent adjacent channel contours), but WSD power levels must be reduced as described to avoid interference. The difference in allowable power levels for these adjacent channel operation cases is related to the WSD proximity to the adjacent channel transmitter (where more power is allowed closer to the incumbent transmitter), and to the class of TV service that is being protected.

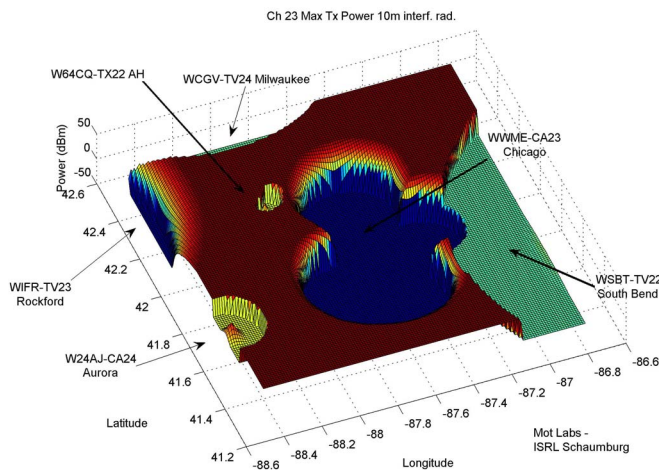


Fig. 5. Geo-location database plot of maximum allowed WSD transmit power level (EIRP) for Ch. 23 in the Chicago area.

A combination of channel power plots can be overlaid to examine overall TVWS channel availability for a given geographic region. WSD channel availability is typically specified by a minimum desirable transmit power level for the cognitive radio link. For example, we would expect fewer channels to be available for WSDs at higher power levels than at lower power levels for a given region, since channel availability is a direct function of maximum allowable WSD transmit power level per channel. Fig. 6 shows a plot of the number of available UHF WSD channels allowing at least 30 dBm of transmit power for the Schaumburg, IL area. Note that the available spectrum is highly spatially dynamic, being directly related to the protected service areas of licensed incumbents. In many cases, the allowance of WSD operation inside of adjacent channel contours is critical for spectrum availability (especially in crowded metro areas).

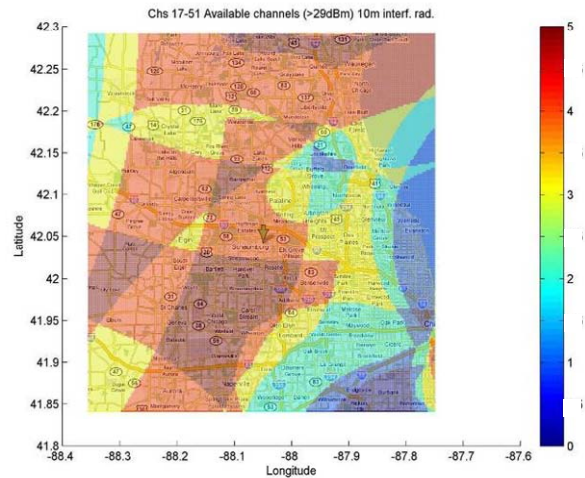


Fig. 6. Geo-location database plot of available UHF channels (17-21) in the Schaumburg, IL area.

B. Geo-location Database Implementation Cost

The computations described above can be implemented in real-time in a low-cost WSD, based on current device (e.g., GPS-determined) location. A demonstration system has been developed by Motorola, in which the geo-location database computations occur on an embedded 7410 PowerPC processor in near real-time. Alternatively, the computations can be performed off-line and stored for a particular geographic region in memory in the WSD.

A more detailed discussion of a TVWS cognitive radio implementation utilizing geo-location database techniques can be found in [15]. This work covers several low-level implementation details.

One method to significantly reduce the implementation complexity of stored geo-location databases is to utilize *location uncertainty* concepts. Starting with the computed high-resolution grid points ($p_{x,y}$) of allowed power levels per location, the lower resolution “quantized” grid points ($P_{x,y}$) are assigned the minimum allowed power within the new

resolvable area quanta (A) centered on the low-resolution grid points (X,Y). Basically, for a given bounded geographic region A (or desired spatial resolution), the worst case higher resolution WSD operating point is chosen per channel over that region. In this case, the lower bound of all higher spatial resolution computed maximum allowable transmit power levels $p_{x,y}$ are taken into account for each lower resolution stored database point ($P_{X,Y}$):

$$P_{X,Y} = \min_{x,y \in A(X,Y)}(p_{x,y}) \quad (4)$$

This conservative method ensures that a WSD can transmit at a given (lower bound) power level without violating interference constraints as long as it operates in the bounded geographic region (A). Figure 7 shows an example of an arbitrary geo-location database resolution reduction from the described techniques.

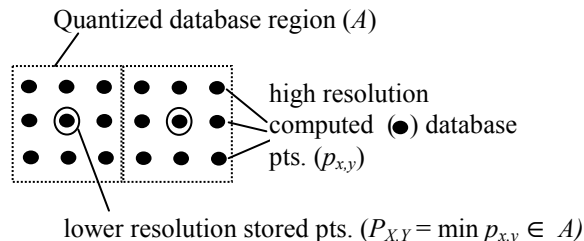


Fig. 7. Arbitrary geo-location database resolution reduction technique

Using these techniques, a WSD could store database results at a resolution well below the required (i.e., FCC mandated) spatial resolution, thus reducing geo-location database implementation complexity while still meeting the required database operating requirements. The general trade-off is the larger the WSD location uncertainty region, the lower the allowed WSD transmit power level. The method can be used to significantly (e.g., $>10x$) reduce the size of stored geo-location databases. In addition, variable spatial resolutions (A) may be stored in the database, with lower resolutions being reserved for areas where the WSD is less likely to operate in, and higher resolutions utilized for common WSD operating regions [14]. Alternatively, highly mobile WSDs may utilize location uncertainty techniques to reduce real-time geo-location database queries (by only requiring database access at larger spatial intervals than specified when in motion). The described methods can be utilized to store very large geo-location databases, or reduce communications bandwidth to a geo-location database server (e.g., for mobile WSDs).

V. SPECTRAL UTILIZATION EFFICIENCY

All WSDs can be judged by how efficiently they utilize the white spaces. Geo-location database enabled WSDs will utilize the TVWS spectrum much more efficiently than their sensing-only counterpart WSDs. This is primarily due to the ability of

geo-location enabled WSDs to accurately determine protected service contours. Sensing-only WSDs must sense incumbent signals down to very low levels (e.g., -116 dBm for DTV transmissions) in order to combat hidden-node effects and other localized sensing phenomena (e.g., fading, shadowing, building penetration losses, etc.). In addition, portable sensing-only units will suffer from low antenna heights, and possibly low antenna gains (due to form factor restrictions and polarization mismatch), all of which make sensing incumbent signals more challenging, and require lower incumbent detection thresholds.

Assuming that the required UHF band DTV incumbent detection level is -116 dBm (or about 16dBu) due to the above issues, using F(50,90) DTV signal propagation modeling at 9m antenna heights, the average DTV transmitter protected service area over-estimation will be roughly 3.5x for an omnidirectional DTV transmitter antenna. Another way to look at this is that an area equal to 2.5 times the DTV station's service area is nominally unused by sensing-only WSDs due to the extremely low detection levels needed to combat the above signal reducing effects. Since this unused area is technically outside of the protected service area for the station, a vast majority of it could have been utilized. Considering that an average full-power DTV station (e.g., 400kW ERP, 400m HAAT) can have a coverage area of about 30,000km², this means a significant under-use of white space spectrum will occur in sensing-only devices. Fig. 8 illustrates the nominal over-estimation of contour area in sensing-only WSDs.

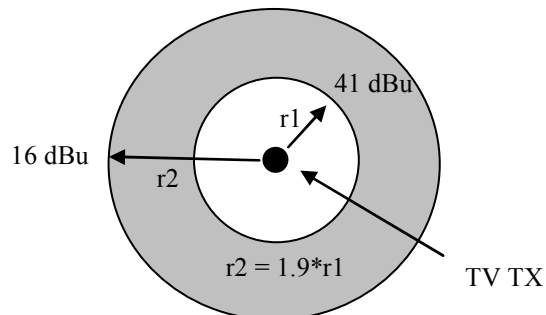


Fig. 8. Under-utilized (wasted) spectrum area (shaded region) using sensing-only techniques

This analysis also assumes that the sensing-only WSD does intelligent detection of the DTV signal to distinguish it from other background noise and interference sources (which will almost certainly exceed -116 dBm levels, even in narrow observation bandwidths). Note again that the IEEE 802.22 standard has proposed the -116 dBm DTV detection level for outdoor, horizontally polarized antennas at 9 m nominal height.

Furthermore, certain incumbent signals, such as low-power and full-power TV transmissions have drastically different protection requirements, though the same modulation is utilized over the air. For example, a low power low-VHF band digital TV transmitter has a 15 dB lower protected service contour level than its full-power DTV counterpart (see Table I above). Sensing-only WSDs have no method to distinguish

low-power DTV signals from full-power DTV signals, since they both utilize identical ATSC modulation. Therefore, a WSD will be forced to protect low-power DTV stations as if they were their full-power counterparts. Using fourth law propagation, this 15 dB contour difference would result in an omni-directional protected service area reduction of 82%, meaning that a sensing-only WSD effectively let 4/5 of the equivalent full-power DTV station's coverage area lie fallow when the station is truly a low-power transmitter. In general, for a given indistinguishable difference in protected service contour levels (Δ_c) to a sensing-only WSD, the normalized percentage of wasted (unused) WSD operational area (A_w) is nominally

$$A_w = \left(1 - \left(10^{-(\Delta_c/40)}\right)^2\right) \times 100 \quad (5)$$

for an incumbent with a circular or omni-directional service area (assuming fourth-law propagation).

VI. OTHER GEO-LOCATION DATABASE CONSIDERATIONS

Aside from higher spectral utilization efficiency, geo-location database approaches have several other advantages. Since geo-location enabled WSDs will be expected to periodically consult (e.g., on a weekly or daily basis) an incumbent database (such as the FCC's CDBS) to obtain incumbent transmitter updates for the band, several types of field interference issues and new services may be addressed dynamically by regulators. Note that a third party may be required to maintain the incumbent databases, though incumbent transmitter information would likely remain similar to the FCC CDBS format.

In addition to licensed transmitter information stored in incumbent databases, interference protection requirements such as those in Table I and II may also be stored in the incumbent database, at whatever granularity (e.g., per-station type, per-region, per-individual station) is desired. This technique would allow regulators to readily address interference issues in the field.

For more specific interference cases, a *mirrored incumbent database* could be maintained and altered. A mirrored database is essentially a copy of the nominal incumbent database, with potential modifications to station parameters or protection requirements. For example, if a particular TV station was observing interference to its service in its southern viewing areas, the station's antenna pattern to the south and protection requirements could be modified (i.e., increased) in the mirrored database to correct the interference issues (since geo-location enabled WSDs would "pick-up" the new information at the next regularly scheduled incumbent database update, and would expand protection in those areas). Note that there is essentially no additional implementation costs for this benefit, since the normal geo-location computation algorithms remain unchanged.

Similarly, new services in the TV bands could be added into

the database to address future systems. This may include not only completely new services (such as DTV a decade ago), but also existing services such as fixed wireless microphone deployments in limited areas. As long as the deployments can be planned ahead of time (before the nominal incumbent database update cycle), such services could be protected, even on an hourly basis if desired (assuming that hourly usage information is also contained in the database). One good example of this capability would be large events like the NFL Superbowl, where dozens of wireless microphones are utilized around a sports stadium for a limited period of time. Periodic (e.g., weekly) services or events could be effectively addressed in a similar manner. As long as the new services follow the same framework of specified propagation modeling, protected service contour levels, and interference protection requirements (which virtually all systems would), the database method is readily adaptable to changes in services.

The notion of service priority can also be incorporated into the database. In this manner, an orderly co-existence between both licensed and unlicensed devices can be achieved [16]. In this scenario, for example, licensed full-power broadcast services and T-band LMR Public Safety systems would have the highest priority, followed by licensed low-power broadcast services, followed by secondary licensed applications such as Part 74 news gathering wireless microphones. The remainder of unlicensed services in the TV bands could contain reasonable priorities (e.g., with public-safety WSDs having higher priority than typical unlicensed wireless microphones). Note that disabling beacon techniques, such as the 802.22.1 beacon also contain provisions for service priority. The concept of registration for unlicensed devices may also afford both a higher level of protection for those devices, as well as allow the tracking of interference issues in the field.

VII. CONCLUSION

The use of geo-location databases for incumbent protection and efficient white space spectrum utilization has been discussed. A detailed application of geo-location databases for TV-band incumbents has been described, along with some important computational and implementation complexity reduction techniques. Specific interference modeling methods have been highlighted, as well as areas where the interference analysis is highly conservative. Several additional advantages of a dynamically updated database framework were also discussed, including the ability to continuously adjust interference protection parameters in the field, and readily add new services to the database.

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