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Geolocation databases for white space devices in the UHF TV bands: Specification of maximum permitted emission levels

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Abstract — **In this paper we present the detailed calculations which a geolocation database would need to perform in order to derive *location-specific* maximum permitted emission levels for white space devices (WSDs) operating in digital terrestrial TV (DTT) bands. We introduce a novel methodology for the calculation of such emission levels, whereby the extent of protection afforded to the DTT service is specified in terms of a maximum permitted degradation in the DTT service *location probability*. We illustrate how national DTT network planning models can be used to provide the necessary parameters for a geolocation database to perform the necessary calculations. We explain how the calculated emission levels need to be post-processed in order to derive consistent WSD regulatory emission limits for the simultaneous protection of multiple DTT channels. We finally use numerical examples to show that the resulting WSD regulatory emission limits can be quite high in areas where the DTT coverage quality is good and the DTT service is therefore relatively immune to interference from WSDs.**

Index Terms—**White space devices, cognitive radios, geolocation database, interference, spectrum management, regulation.**

I. INTRODUCTION

In recent years there has been a great deal of interest from both academia and the communications industry in the use of UHF digital terrestrial TV (DTT) frequencies by so-called *cognitive radios* or *white-space devices* (WSDs) [1]. The high level of interest in this field has been counter-balanced by the obligation of national regulatory authorities worldwide to ensure that appropriate levels of protection are afforded to the incumbent DTT services.

Much of the research in this field has been directed toward the operation of *autonomous* WSDs. These devices detect the presence of an existing DTT service via advanced spectrum *sensing* techniques and algorithms, and only radiate where interference to the DTT service is deemed unlikely. It is inevitable that the specification of the *regulatory* emission limits for the operation of such autonomous WSDs in DTT bands has to be based on a) worst-case geometries relating to the interfering WSD and the victim DTT receiver, and b) worst-case sensing (i.e., hidden node) environments. Consequently, adequate protection of the DTT service can result in very stringent (low) WSD regulatory emission limits and sensing levels, both applied uniformly at all locations. This simultaneously reduces the utility of autonomous WSDs and increases their complexity.

The above issue can be resolved if the WSDs operate with assistance from a geolocation database [2]. This is because the impact of harmful interference on a DTT receiver is a strong function of the quality of the DTT coverage in the geographical area where the DTT receiver is located. The implication is that the regulatory emission limits for a *database-assisted* WSD can be significantly increased in areas where the DTT signal-to-noise-plus-interference ratio is high in the absence of WSDs; i.e., where the DTT coverage quality is good. This not only significantly improves the utility of the WSDs, but also removes the need for sensing and detection of very low-power DTT signals (as required by autonomous WSDs). A WSD would only need to report its location to the database and in return receive information with regards to the maximum emission levels with which it can radiate.

In order to afford appropriate levels of protection to the DTT service, it is necessary for the database to specify the maximum permitted WSD emission levels across all DTT channels and in all geographic locations where the DTT service is being used. To accomplish this, the database needs access to the following information:

1) The quality of national DTT coverage to within a suitable spatial resolution.
2) A suitable criterion (or metric) for quantifying and specifying a permitted level of interference to the DTT service.
3) Specified interferer-victim *reference* co-existence geometries for which the WSD regulatory emission limits would result in the aforementioned permitted level of interference.
4) Appropriate values of WSD-to-DTT protection ratios defined as a function of interferer-victim frequency separation and as a function of the received wanted DTT power at the victim DTT receiver.

5) A methodology for deriving appropriate and consistent WSD regulatory emission limits for simultaneous protection of multiple DTT channels.

In this paper we examine each of the above items. The regulatory and standardization issues involved in the implementation of such geolocation databases are addressed in the appendix to this paper.

In Section (II) we first introduce the DTT *location probability* as a measure for quantifying the quality of national DTT coverage. We then describe how WSD emissions levels can be specified so that they result in a specific permitted degradation in DTT location probability. We also describe the importance of the spectral leakage of WSDs in defining the WSD-to-DTT protection ratios, and explain why it is important that the spectral leakage characteristics of WSDs are specified by appropriate technical standardization organizations before geolocation databases can be established.

In Section (III) we summarize the sequence of calculations that must be performed by the geolocation database. We emphasize that the database must consider both co-channel and adjacent-channel interference scenarios. We explain the need for *reference* interferer-victim geometries for the protection of DTT channels that are used by the DTT service in the same geographical location as the WSD. We also describe how the various calculated WSD in-block and out-of-block EIRP levels have to be reconciled in order to obtain a consistent set of *regulatory emission limits* over all DTT frequencies.

We end the paper in Section (IV) with numerical examples derived from the output of the DTT network planning model in the United Kingdom. It should be emphasized that the numerical values of the parameters used in a geolocation database can be specified independently by different national regulatory authorities based on their particular circumstances and policies. The database parameter values presented in this paper are for illustration purposes only.

II. GEOLOCATION DATABASE AND LOCATION PROBABILITY

The DTT *location probability* is defined as the probability with which a DTT receiver would operate correctly at a specific location; i.e., the probability with which the median wanted signal level is appropriately greater than a minimum required value.

Location probability is widely used in the planning of DTT networks in order to quantify the quality of coverage, and in the UK is typically calculated for every 100 m × 100 m pixel across the country. The presence of any interferer naturally results in a reduction of the DTT location probability. Such a reduction is therefore a highly suitable metric for specifying regulatory emission limits for WSDs operating in DTT frequencies.

A. Definition of location probability

Consider a pixel where the DTT location probability is q_1 in the absence of interference from systems other than DTT. Then we can write (in the linear domain)

$$q_1 = \Pr\left\{ P_{\mathrm{S}} \geq P_{\mathrm{S,min}} + \sum_{k=1}^{K} r_{U,k} P_{U,k} \right\} = \Pr\{P_{\mathrm{S}} \geq U\} \qquad (1)$$

where $\Pr\{A\}$ is the probability of event A, P_{S} is the received power of the wanted DTT signal, $P_{\mathrm{S,min}}$ is the DTT receiver's (noise-limited) reference sensitivity level[1], $P_{U,k}$ is the received power of the k^{th} unwanted DTT signal, and $r_{U,k}$ is DTT-to-DTT protection ratio for the k^{th} DTT interferer.

Equation (1) is a direct result of the definition of protection ratio; i.e., the minimum ratio of wanted signal power to interferer signal power (as measured at the input to the receiver) required for the correct operation of the receiver.

In the planning of DTT networks, $P_{\mathrm{S\,(dBm)}}$ and each of the individual terms $P_{U,k\,\mathrm{(dBm)}}$ are modelled as real Gaussian random variables. Note that in (1), the powers are summed in the linear domain. For this reason, the most accurate way of calculating the probability q_1 is to use a Monte Carlo simulation where a large number of trials are performed with values for each variable generated according to their log-normal distribution. An approximation of the exact calculation could also be performed as described next.

Strictly speaking, the location probability q_1 should be computed directly via Monte Carlo simulations. However, the terms $P_{\mathrm{S\,(dBm)}}$ and $U_{\mathrm{(dBm)}}$ are typically approximated[2] as Gaussian random variables with medians $m_{\mathrm{S\,(dBm)}}$ and $m_{U\,\mathrm{(dBm)}}$, and standard deviations $\sigma_{\mathrm{S\,(dB)}}$ and $\sigma_{U\,\mathrm{(dB)}}$, respectively. The terms $m_{U\,\mathrm{(dBm)}}$ and $\sigma_{U\,\mathrm{(dB)}}$ can be derived via numerical techniques such as the Schwartz-Yeh algorithm or Monte Carlo simulations. The relationship between the parameters $q_1, P_{\mathrm{S\,(dBm)}}$ and $U_{\mathrm{(dBm)}}$ in a pixel is illustrated in Figure 1 below.

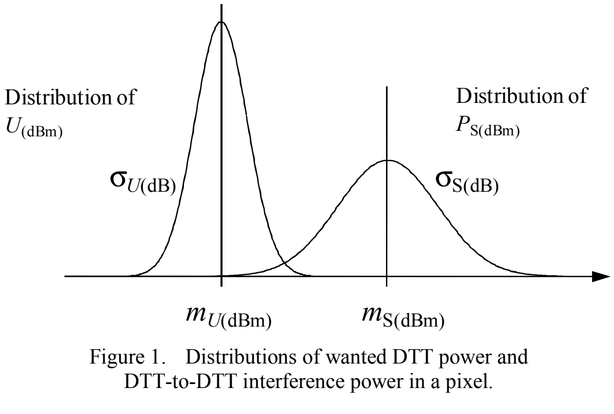

Figure 1. Distributions of wanted DTT power and DTT-to-DTT interference power in a pixel.

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[1] The reference sensitivity level of a receiver is the minimum wanted signal power for which the receiver can operate correctly in a noise-limited environment.

[2] This approximation (with medians and standard deviations derived via Schwartz-Yeh) is used in the UK DTT network planning model.

From Equation (1), and based on the above approximation, the location probability can be readily expressed in closed form as

$$q_1 = 1 - \frac{1}{2}\operatorname{erfc}\left\{ \frac{1}{\sqrt{2}} \frac{m_{\mathrm{S(dBm)}} - m_{U\mathrm{(dBm)}}}{\sqrt{\sigma^2_{\mathrm{S(dB)}} + \sigma^2_{U\mathrm{(dB)}}}} \right\}. \qquad (2)$$

Numerical examples of this approach are presented in Section (IV).

B. Calculation of WSD in-block EIRP subject to a specific degradation in DTT location probability

In the previous section we showed how the DTT location probability can be calculated as a function of the median and standard deviations of the wanted DTT signal power and the DTT-to-DTT interference power in a given pixel.

Let us now consider a WSD which operates at a carrier frequency $f_{\mathrm{WSD}} = f_{\mathrm{DTT}} + \Delta f$, where f_{DTT} is the DTT carrier frequency. Let us also assume that the WSD radiates with an in-block EIRP of $P^{\mathrm{WSD}}_{\mathrm{IB}}$ over a channel bandwidth of 8 MHz. For the special case of co-channel operation, $\Delta f = 0$.

The presence of the WSD interferer will inevitably reduce the DTT location probability from q_1 to $q_2 = q_1 - \Delta q$. Assuming a coupling gain, G, the WSD interferer power at the DTT receiver is given by the product $G\,P^{\mathrm{WSD}}_{\mathrm{IB}}$. Following the framework described in (1), we may write (again in the linear domain)

$$q_2 = \Pr\left\{ P_{\mathrm{S}} \ge P_{\mathrm{S,min}} + \sum_{k=1}^{K} r_{U,k} P_{U,k} + r(\Delta f)\, G\, P^{\mathrm{WSD}}_{\mathrm{IB}} \right\} \qquad (3)$$

The coupling gain includes path loss, receiver antenna gain, as well as receiver antenna angular and polarization discriminations. The coupling gain, $G_{\mathrm{(dB)}}$ is typically modelled as a Gaussian random variable with a median value, $m_{G\,\mathrm{(dB)}}$, and a standard deviation $\sigma_{G\mathrm{(dB)}}$.

As explained for the case of Equation (1), strictly speaking, q_2 should be computed via Monte Carlo simulations. However, as for the case of q_1, an approximation could be made in order to derive q_2 analytically. By expanding (3), we have

$$\begin{aligned} q_2 &= \Pr\left\{ P_{\mathrm{S}} \ge P_{\mathrm{S,min}} + \sum_{k=1}^{K} r_{U,k} P_{U,k} + r(\Delta f)\, G\, P^{\mathrm{WSD}}_{\mathrm{IB}} \right\} \\ &= \Pr\left\{ P_{\mathrm{S}} \ge U + r(\Delta f)\, G\, P^{\mathrm{WSD}}_{\mathrm{IB}} \right\} \\ &= \Pr\left\{ r(\Delta f)\, G P^{\mathrm{WSD}}_{\mathrm{IB}} \le P_{\mathrm{S}} - U \right\} \\ &= \Pr\left\{ r(\Delta f)\, G P^{\mathrm{WSD}}_{\mathrm{IB}} \le Z \right\} \\ &= \Pr\left\{ P^{\mathrm{WSD}}_{\mathrm{IB}} \le \frac{1}{r(\Delta f)\, G} Z \right\} \\ &= \Pr\left\{ P^{\mathrm{WSD}}_{\mathrm{IB\,(dBm)}} \le Z_{\mathrm{(dBm)}} - G_{\mathrm{(dB)}} - r(\Delta f)_{\mathrm{(dB)}} \right\}. \end{aligned} \qquad (4)$$

Then assuming that $Z_{\mathrm{(dBm)}}$ is a Gaussian random variable with a median value, $m_{Z\,\mathrm{(dBm)}}$, and a standard deviation $\sigma_{Z\,\mathrm{(dB)}}$, the immediate implication of (4) is that (in the logarithmic domain) the maximum permitted WSD in-block EIRP is given by

$$\begin{aligned} P^{\mathrm{WSD}}_{\mathrm{IB\,(dBm)}} \le\; & m_{Z\,\mathrm{(dBm)}} - m_{G\,\mathrm{(dB)}} - r(\Delta f)_{\mathrm{(dB)}} \\ & - \mu(q_2)\sqrt{\sigma^2_{Z\,\mathrm{(dB)}} + \sigma^2_{G\,\mathrm{(dB)}}} - \mathrm{IM}_{\mathrm{(dB)}}\,. \end{aligned} \qquad (5)$$

The term $\mathrm{IM}_{\mathrm{(dB)}}$ is an interference *safety margin* which can be judiciously set by the database to provide an additional margin of protection to DTT services[3]. The term $\mu(q_2)$ represents the number of standard deviations which would allow a location probability of q_2 to be achieved. In other words

$$1 - q_2 = \frac{1}{2}\operatorname{erfc}\left\{ \frac{\mu}{\sqrt{2}} \right\}$$

or

$$\mu(q_2) = \sqrt{2}\operatorname{erfc}^{-1}\left\{ 2(1 - q_2) \right\}. \qquad (6)$$

Note that the median $m_{Z\,\mathrm{(dBm)}}$ and standard deviation $\sigma_{Z\,\mathrm{(dB)}}$ would need to be derived via numerical techniques such as the Schwartz-Yeh algorithm or Monte Carlo simulations. Numerical examples of the application of (5) and (6) are presented in Section (IV).

C. Calculation of WSD out-of-block EIRP subject to a specific degradation in location probability

Equation (5) explicitly describes how the maximum permitted WSD in-block EIRP can be calculated such that it results in a degradation, $\Delta q = q_2 - q_1$, in the DTT location probability. However, Equation (5) also implicitly specifies the maximum permitted WSD out-of-block EIRP through the use of WSD-to-DTT protection ratios, $r(\Delta f)$.

This is because the protection ratio is a function of both the spectral leakage of the WSD transmitter and the spectral selectivity[4] of the DTT receiver. Specifically, the protection ratio $r(\Delta f)$ is defined (in the linear domain) by

$$\begin{aligned} r(\Delta f) &= \frac{P^*_{\mathrm{S}}}{P^*_{\mathrm{AC}}} = \frac{P^*_{\mathrm{S}}}{P^*_{\mathrm{I}}}\frac{P^*_{\mathrm{I}}}{P^*_{\mathrm{AC}}} = r(0)\frac{1}{\mathrm{ACIR}(\Delta f)} \\ &= r(0)\left(\mathrm{ACLR}^{-1}_{\mathrm{WSD}}(\Delta f) + \mathrm{ACS}^{-1}_{\mathrm{DTT}}(\Delta f) \right) \end{aligned} \qquad (7)$$

where * denotes the value at the point of receiver failure, P_{I} is the interference power, and P_{AC} is the power of the adjacent channel interferer. ACIR is the adjacent-channel interference ratio, $\mathrm{ACLR}_{\mathrm{WSD}}$ is the adjacent-channel leakage

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[3] The value of this margin might, for example, be increased in response to a proliferation of WSDs and an increase in the potential for aggregate interference from multiple WSDs to DTT services.

[4] The selectivity can derived from measurements of the protection ratios of DTT receivers in the presence of adjacent channel test interferers. The selectivity of the DTT receivers is then calculated by accounting for the contribution to interference caused by the spectral leakage of the test interferer.

ratio of the WSD transmitter, and $\mathrm{ACS}_{\mathrm{DTT}}$ is the adjacent-channel selectivity of the DTT receiver[5].

If the receiver selectivity is defined as a function of the wanted signal power, then the protection ratios can also be used to implicitly model the non-linear behaviour (*overloading*) of the DTT receiver. This is an important aspect of any modeling, since the adjacent channel selectivity of DTT receivers invariably reduces when the receivers are exposed to high power signals [3].

It is evident that the protection ratio $r(\Delta f)$ in Equation (7) implicitly identifies the spectral leakage of the WSD via the adjacent-channel leakage ratio $\mathrm{ACLR}_{\mathrm{WSD}}(\Delta f)$.

Then, by definition, the maximum permitted WSD out-of-block EIRP level is given (in the logarithmic domain) as

$$P^{\mathrm{WSD}}_{\mathrm{OOB\,(dBm)}}(\Delta f) = P^{\mathrm{WSD}}_{\mathrm{IB\,(dBm)}} - \mathrm{ACLR}_{\mathrm{WSD}}(\Delta f)_{\mathrm{(dB)}}\,. \qquad (8)$$

Naturally, the extent of interference caused by a WSD is a function of both its in-block and out-of-block EIRP levels. This is evident from Equations (3), (7) and (8).

Since the ACLR of the WSD is implicitly incorporated in the protection ratio used in Equation (3) to derive the maximum permitted WSD in-block EIRP levels, it is important that technical standardization organizations specify the ACLR of WSDs so that they can be appropriately used by geolocation databases. Otherwise the geolocation database would need to be established based on an ACLR value that is only *representative* of the spectral leakage performance of WSDs. This would result in the database specifying over-stringent regulatory WSD in-block EIRP limits, since it is likely that national regulatory authorities would err on the side of caution, and underestimate the ACLR of the WSDs absent any standardized technology specifications.

For the purposes of the numerical examples in Section (IV), we set the ACLR of the WSD to be equal to the ACLR of other broadly similar communication devices; e.g., LTE terminal stations (for mobile-WSDs) and LTE base stations (for fixed-WSDs).

III. DATABASE CALCULATIONS & REGULATORY LIMITS

In this section we summarize the type of calculations which a geolocation database must perform in order to specify *location-specific* WSD *regulatory* emission limits applicable across all potentially affected DTT frequencies.

Specifically, for a given geographic pixel, the database must examine all relevant co-channel and adjacent-channel interference scenarios with respect to the victim DTT channels. Each WSD-to-DTT frequency separation then results in specific maximum permitted WSD in-block and out-of-block EIRP levels required for a permitted level of interference to the DTT service. We describe these calculations further in Section (IIIA).

Subsequently, we show that the database must reconcile all the calculated WSD in-block and out-of-block maximum permitted EIRP levels for the given pixel, in order to derive the appropriate WSD regulatory emission limits across all DTT frequencies. We illustrate this via a simple example in Section (IIIB).

A. Calculation of location-specific WSD in-block and out-of-block EIRP levels for a given frequency separation between WSD and victim DTT channel

The following calculations must be performed for any given pixel where the WSD operates, and for all frequency separations between the WSD's operating channel and the victim DTT channels:

1) The geolocation database must be aware of the frequencies, median $m_{\mathrm{S\,(dBm)}}$ and standard deviation $\sigma_{\mathrm{S\,(dB)}}$ of the received DTT signal power, the median $m_{U\,\mathrm{(dBm)}}$ and standard deviation $\sigma_{U\,\mathrm{(dB)}}$ of the DTT interferer powers, as well as the resulting DTT location probability q_1 in each geographic pixel. The above parameters can be extracted from the national DTT network planning model. In the absence of such a model, the above parameters can be calculated explicitly based on the technical characteristics and locations of the DTT transmitters, as described in Equation (1).
2) The geolocation database must then calculate the median and standard deviation of the coupling loss between the WSD interferer and victim DTT receiver. This requires the use of appropriate propagation models and interferer-victim geometries. For victim DTT channels that are used by the DTT service in the same pixel as the WSD, the coupling gain must be based on a *reference coexistence geometry* (see Section IV) that is deemed suitable in the context of protecting the DTT platform. Such a reference geometry is necessary because the precise spatial separation between the WSD and a victim DTT receiver within the given pixel cannot be known by the database. For victim DTT channels that are not used by the DTT service in the same pixel as the WSD, the coupling gain can be based on the actual spatial separation between the pixel where the WSD operates and the pixel where the DTT channel is used by the DTT service.
3) The geolocation database must also assume a maximum permitted degradation, $\Delta q = q_1 - q_2$, in the DTT location probability of pixels where the DTT services are used. The permitted degradation can be different in different pixels. For example, it may be set according to the

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[5] The ACLR of a signal is defined as the ratio of the signal's power (nominally equal to the power over the signal's pass-band) divided by the power of the signal when measured at the output of a (nominally rectangular) receiver filter centred on an adjacent frequency channel. The ACS of a receiver is defined as the ratio of the receiver's filter attenuation over its pass-band divided by the receiver's filter attenuation over an adjacent frequency channel. It can be readily shown that $\mathrm{ACIR}^{-1} = \mathrm{ACLR}^{-1} + \mathrm{ACS}^{-1}$. The ACIR is defined as the ratio of the power of an adjacent-channel interferer as received at the victim, divided by the interference power "experienced" by the victim receiver as a result of both transmitter and receiver imperfections.

number of households in each pixel; e.g., smaller degradations may be mandated in more populated pixels.

4) The geolocation database must assume an appropriate ACLR for the WSD. This ACLR would be a function of the frequency separation Δf between the WSD and the victim DTT channel. Combined with measured values of DTT receiver ACS, the database must calculate appropriate WSD-to-DTT protection ratios $r(\Delta f)$ as described in Equation (7).
5) With the above parameters calculated, the database can readily compute the maximum permitted WSD in-block and out-of-block EIRPs given by

$$P^{\mathrm{WSD}}_{\mathrm{IB\,(dBm)}} \le m_{Z\,\mathrm{(dBm)}} - m_{G\,\mathrm{(dB)}} - r(\Delta f)_{\mathrm{(dB)}} - \mu(q_2)\sqrt{\sigma^2_{Z\,\mathrm{(dB)}} + \sigma^2_{G\,\mathrm{(dB)}}} - \mathrm{IM}_{\mathrm{(dB)}},$$

$$P^{\mathrm{WSD}}_{\mathrm{OOB\,(dBm)}}(\Delta f) \le P^{\mathrm{WSD}}_{\mathrm{IB\,(dBm)}} - \mathrm{ACLR}_{\mathrm{WSD}}(\Delta f)_{\mathrm{(dB)}},$$

and as described in Equations (5) and (7). Needless to say, the out-of-block EIRP calculation is not applicable to co-channel interference scenarios.

To account for the potential inaccuracies (or estimation errors) in the reported location of a WSD within a pixel, it would be prudent for the above maximum permitted in-block and out-of-block EIRPs levels for the operation of a WSD within a pixel to be specified as the minimum of those calculated for M surrounding pixels. This is illustrated in Figure 2 for $M = 8$. This approach would also account for the cases where a WSD within a pixel is actually in the proximity of a victim in a neighbouring pixel.

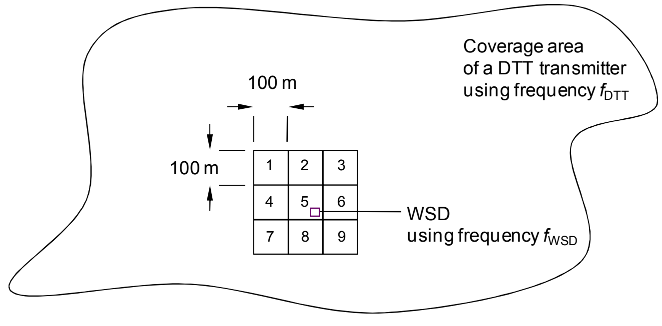

Figure 2. Calculations over surrounding pixels to account for errors in the estimation of WSD locations.

B. *Reconciliation of the calculated WSD in-block and out-of-block EIRP levels to derive regulatory EIRP limits over all DTT channels*

It is important to note that all DTT channels can be potential victims of a WSD operating in a given pixel. However, the critical cases correspond to those DTT channels that have a small frequency separation from the WSD in-block emissions and/or those DTT channels that are used by the DTT service in locations close to the pixel where the WSD operates. It is therefore important that all cases (or at least the critical cases) are examined by the database, and that the appropriate WSD in-block and out-of-block EIRP levels are calculated appropriately for each case.

Having performed these calculations (as described in Section IIIA), it is important that the in-block and out-of-block EIRP limits are reconciled in such a way so as to provide a consistent set of WSD regulatory emission limits over (and for the simultaneous protection of) all DTT channels. We illustrate this subtle point via a simple example.

Let us consider an artificial situation where there exist a total of only 3 DTT channels with centre frequencies f_1, f_2, and f_3. Let us also focus on a given pixel where the WSD operates. To simplify the description, and for illustrative purposes only, we a) ignore the standard deviations of all wanted and interferer signals, b) ignore DTT-to-DTT interference, and c) assume that the receiver reference sensitivity level is small compared to the wanted signal power and can be ignored[6]. Consequently, a victim DTT receiver is protected so long as the received WSD interferer power is less than the received DTT signal power minus the relevant protection ratio.

Figure 3 illustrates the assumed spatial pattern of the usage of the three DTT channels. As can be seen, the WSD operates in a given pixel within which the DTT network uses frequency f_2 (hence a reference interferer-victim separation of, say, only 22 m), while frequencies f_1 and f_3 are used in other distant pixels, the closest of which (or more precisely, those that are most susceptible to interference) are 5 and 20 km from the pixel of interest, respectively. The relevant coupling gains can be derived based on the above geometries.

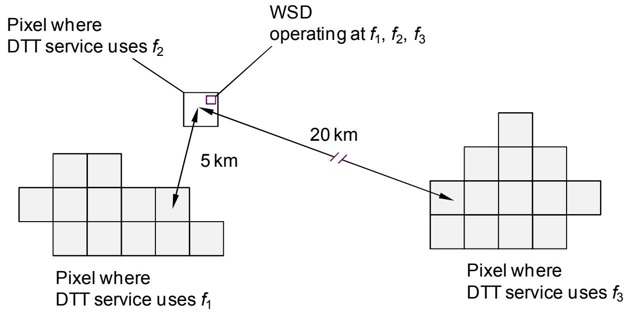

Figure 3. Usage of frequencies f_1, f_2, and f_3 by the WSD and the DTT service. The nearest pixels where f_1 and f_3 are used by the DTT service are 5 and 20 km away, respectively.

As described in Section (IIIA), for each combination of WSD operating frequency and victim DTT frequency, the database can calculate the maximum permitted in-block and out-of-block EIRPs for a WSD transmitting in a given pixel (subject to a permitted level of interference to DTT).

The database must then generate the following 3 tables for the pixel of interest in Figure 3 where the WSD operates. Tables I, II, and III show the calculated maximum permitted EIRP levels for a WSD operating in the pixel at frequency f_1, f_2 and f_3, respectively.

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[6] For a receiver noise figure of 7 dB and a noise equivalent bandwidth of 7.6 MHz, the DTT receiver noise floor is -98 dBm. Then a co-channel protection ratio of 16 dB implies a reference sensitivity level of -82 dBm.

TABLE I. ILLUSTRATIVE IN-BLOCK AND OUT-OF-BLOCK EMISSION LIMITS CALCULATED FOR A WSD OPERATING IN FREQUENCY F$_1$.

WSD operates in 8 MHz channel centred at frequency $f_{WSD} = \boldsymbol{f_1}$				
DTT (8 MHz) channel centre frequency, f_{DTT}	WSD-to-TV separation (coupling gain)	Protection ratio (dB)	WSD in-block EIRP (dBm) for $f_{WSD} = \boldsymbol{f_1}$	WSD out-of-block EIRP (dBm) over $\boldsymbol{f_{DTT}}$
f_1	5 km (-142 dB)	16	56	N/A
f_2	22 m (-50 dB)	-17	-3	-36
f_3	20 km (-165 dB)	-20	115	79

TABLE II. ILLUSTRATIVE IN-BLOCK AND OUT-OF-BLOCK EMISSION LIMITS CALCULATED FOR A WSD OPERATING IN FREQUENCY F$_2$.

WSD operates in 8 MHz channel centred at frequency $f_{WSD} = \boldsymbol{f_2}$				
DTT (8 MHz) channel centre frequency, f_{DTT}	WSD-to-TV separation (coupling gain)	Protection ratio (dB)	WSD in-block EIRP (dBm) for $f_{WSD} = \boldsymbol{f_2}$	WSD out-of-block EIRP (dBm) over $\boldsymbol{f_{DTT}}$
f_1	5 km (-142 dB)	-17	89	56
f_2	22 m (-50 dB)	16	-36	N/A
f_3	20 km (-165 dB)	-17	112	79

TABLE III. ILLUSTRATIVE IN-BLOCK AND OUT-OF-BLOCK EMISSION LIMITS CALCULATED FOR A WSD OPERATING IN FREQUENCY F$_3$.

WSD operates in 8 MHz channel centred at frequency $f_{WSD} = \boldsymbol{f_3}$				
DTT (8 MHz) channel centre frequency, f_{DTT}	WSD-to-TV separation (coupling gain)	Protection ratio (dB)	WSD in-block EIRP (dBm) for $f_{WSD} = \boldsymbol{f_3}$	WSD out-of-block EIRP (dBm) over $\boldsymbol{f_{DTT}}$
f_1	5 km (-142 dB)	-20	92	56
f_2	22 m (-50 dB)	-17	-3	-36
f_3	20 km (-165 dB)	16	79	N/A

TABLE IV. REGULATORY WSD EMISSION LIMITS.

8 MHz channel centre frequency, f	Regulatory EIRP limit (dBm)
f_1	-3
f_2	-36
f_3	-3

Note that the numerical values in the tables are selected as examples and are only intended to illustrate the manipulations which the database must perform. For simplicity, we assume that the DTT signal power at the victim DTT receiver is -70 dBm in all pixels of interest. This corresponds to poor DTT quality at the edge of coverage. We also assume WSD ACLRs of 33 and 36 dB in the first and second adjacent channels. Combined with ACSs of 56 and 61 dB, and a co-channel protection ratio of 16 dB, this implies protection ratios of -17 and -20 dB in the first and second adjacent channels. Also note that, while for simplicity victim-interferer separation is used as an indicator of the potential for interference, it is actually the coupling gain[7] which is the relevant factor. The maximum permitted WSD in-block EIRP levels are then calculated as the DTT signal power, minus the protection ratio, minus the coupling gain.

Table I indicates that, if a WSD wishes to operate at frequency f_1 in the pixel of interest in Figure 3, then the protection of DTT channel f_2 is the bottleneck case. This is because f_2 is being used by the DTT service in the same pixel as the WSD. For this reason the WSD is only allowed to radiate at most -3 dBm in f_1. Table I also implies that the maximum permitted WSD out-of-block EIRP level is -36 and -39 dBm over frequencies f_2 and f_3 (33 and 36 dB lower than the in-block level of -3 dBm), respectively. The same narrative applies to Tables II and III.

The database now needs to compile the maximum permitted WSD in-block EIRP levels depicted in Tables I, II, and III into a consistent set of regulatory emission limits over frequencies f_1, f_2, and f_3.

Table IV illustrates the required compilation. The regulatory emission limits applicable to the WSD over each DTT frequency channel is the minimum of the calculated maximum permitted in-block EIRP levels derived in each of Tables I, II, and III.

In practice, where we need to establish the permitted WSD emission limits over all UHF DTT channels 21 through to 60, the geolocation database must generate 40 such tables for each pixel wherein the WSD might be located. It is also worth noting that each table should examine the victim pixels that are most susceptible to interference for each DTT channel. Of course such calculations are not required to be performed in real time, and despite the high volume of computations, they are not prohibitively complex.

IV. NUMERICAL EXAMPLES

In this section we demonstrate the methodology presented in the previous sections through a number of numerical examples. It should again be emphasized that the numerical values of the parameters used in a geolocation database can be specified independently by different national regulatory authorities based on their particular circumstances and policies. The database parameter values presented in this section are for illustration purposes only.

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[7] For this example, the coupling gains incorporate path gain (suburban Hata) at 650 MHz, WSD antenna height of 1.5 m, TV receiver antenna height of 10 m, gain of 9.15 dBi, and angular/polarization discrimination of 3 dB.

A. Reference geometries

Different national regulatory authorities may use different reference geometries in the context of co-existence between WSDs and DTT services within the same pixel. For example, in one country only the protection of fixed roof-top DTT reception might be considered, whereas in another country DTT reception with set-top aerials might be protected. In this paper we examine the two geometries described below.

a) Mobile-WSD operation and fixed roof-top DTT reception

Figure 4 shows the relevant reference geometry. This geometry was also used in CEPT Report 30 [4] for the calculation of the emission limits for mobile/fixed communication network terminal stations (user equipment) in the 800 MHz Digital Dividend band.

Here we assume that the WSD is located along the azimuth bore-sight of the DTT receiver's antenna. Also note that for a DTT antenna angular gain pattern which complies with the ITU-R BT.419-3 specifications [3] and with a zero vertical down-tilt, the highest median coupling gain, $m_{G\ (\mathrm{dB})}$, occurs at a horizontal separation of 22 m. The assumed horizontal polarization of the DTT receiver antenna also provides a 3 dB polarization discrimination with respect to a randomly oriented mobile-WSD.

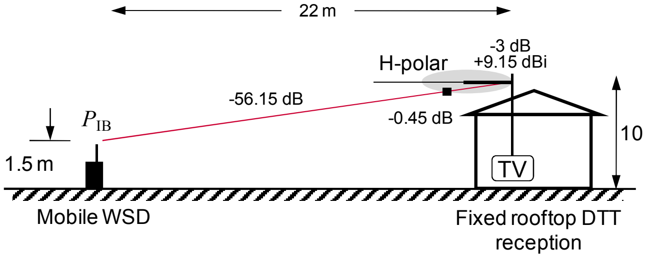

Figure 4. Reference geometry for mobile-WSD. Shown path loss is for a carrier at 650 MHz.

b) Fixed-WSD operation and fixed roof-top DTT reception

Figure 5 shows the relevant reference geometry. This is representative of scenarios where the fixed-WSD and the victim DTT receiver are located on opposite sides of the road, with the WSD again located along the azimuth bore-sight of the DTT receiver's antenna. The assumed horizontal polarization of the DTT receiver antenna would provide a 16 dB polarization discrimination with respect to a opposite-to-DTT (vertically) polarized fixed-WSD transmitter antenna.

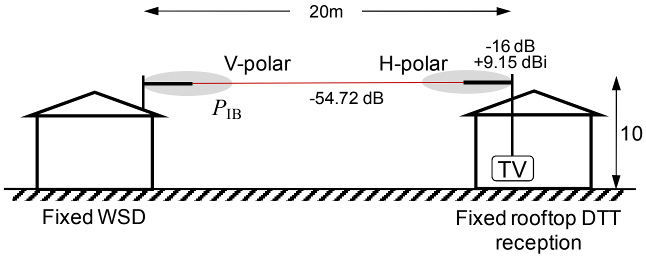

Figure 5. Reference geometry for fixed-WSD. Shown path loss is for a carrier at 650 MHz.

B. Interference safety margin

Depending on their specific circumstances and policies, national regulatory authorities may adopt different values for the interference margin, $\mathrm{IM}_{(\mathrm{dB})}$, in Equation (5). In one possible realization, the interference margin could be set dynamically in order to account for the short-term temporal variation in the number of WSDs operating within any pixel. In another possible realization, the interference margin could be adjusted based on the long-term proliferation of the number of WSDs, or even based on the number of complaints received by viewers of the DTT service. For the examples in this section, we assume $\mathrm{IM}_{(\mathrm{dB})} = 3$ dB.

C. Summary of parameter values

Table V summarizes the values of the various parameters used in the numerical examples of this section. Different national regulatory authorities may adopt other parameter values for use in their authorized geolocation databases.

D. Numerical results

Table VI shows the DTT wanted signal power and DTT interference powers, at an operating frequency of 650 MHz, and for a cluster of 9 adjacent pixels (see Figure 2) at a specific location in the proximity of a DTT transmitter in the United Kingdom. These values are extracted from the UK DTT network planning model. The location probabilities here are close to unity, implying excellent DTT coverage at this location. Note that $P_S >> U$, implying a noise-limited environment.

To place the values of the median wanted DTT signal power, m_S, of Table VI into broader context, Figure 6 shows the cumulative distribution of m_S throughout the coverage area of a specific DTT transmitter in the UK. Pixels which have a DTT location probability of less than 0.7 are not considered as served in the planning of the UK DTT network and are not included in the compilation of the data in Figure 6. As can be seen, the wanted DTT signal power varies from just below -70 dBm at the edge of DTT coverage, up to just below -20 dBm is areas close to the DTT transmitter.

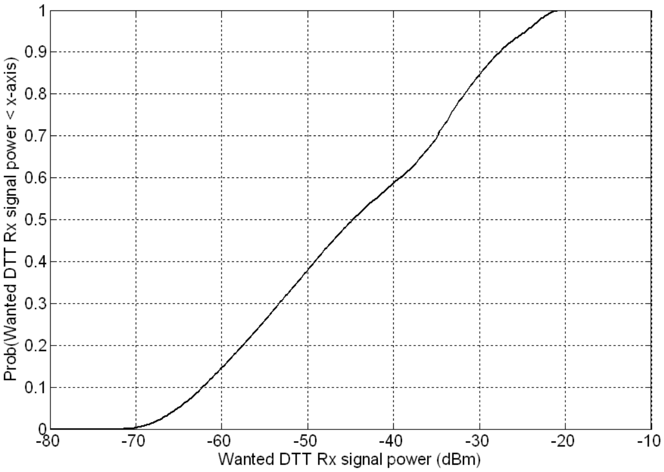

Figure 6. Distribution of median wanted DTT signal power, m_S.

TABLE V. SUMMARY OF DATABASE PARAMETERS, AND THE VALUES USED IN THE NUMERICAL EXAMPLES OF THIS SECTION.

$m_{S\,(dBm)}$, $\sigma_{S\,(dB)}$, $m_{U\,(dBm)}$, $\sigma_{U\,(dB)}$, q_1 The medians and standard deviations of $P_{S\,(dBm)}$ and $U_{(dBm)}$. These are derived for each pixel from the UK DTT network planning model. The location probability q_1 is calculated analytically as described in Equation 2.
$m_{Z\,(dBm)}$, $\sigma_{Z\,(dB)}$ The median and standard deviation of $Z_{(dBm)}$. These are calculated for each pixel via Monte Carlo simulations (see Equation 4).
Δq , $q_2 = q_1 - \Delta q$ Δq is the maximum permitted degradation in DTT location probability within a given pixel. For illustration, we assume that $\Delta q = 0.01$. The WSD in-block EIRP which results in q_2 is derived via the analytical approximation of Equation (5).
f_{DTT} The frequency of the DTT carrier. This is assumed to be 650 MHz.
Δf The frequency offset between the WSD and DTT carriers. This is assumed to be 16 MHz.
WSD adjacent-channel leakage ratio, $ACLR_{WSD}$ Mobile-WSD. The ACLR is set to 36 dB, compatible with $ACLR_2$ of a LTE terminal station [5]. Fixed-WSD. The ACLR is set to 45 dB, compatible with ACLR of a LTE base station [6].
DTT receiver adjacent-channel selectivity, ACS_{DTT} These are derived from measurements of protection ratio [3]. Specifically, for Δf = 16 MHz, we assume that ACS_{DTT} = 61, 58, 42, 35, and 28 dB for m_S = -70, -50, -30, -20, and -12 dBm, respectively. The dependence of the ACS on the wanted signal power implicitly models the non-linear behaviour (overload) of the DTT receiver. We also assume that: $ACS_{DTT} = -500$ dB for $m_S > -12$ dBm, and that $ACS_{DTT} = 61$ dB for $m_S < -70$ dBm.
WSD-to-DTT protection ratio, $r(\Delta f)$ This is derived from the DTT receiver ACS and the WSD ACLR. The co-channel protection ratio $r(0)$ is assumed to be 16 dB (based on measurements [3]).
$IM_{(dB)}$ Interference margin is assumed to be 3 dB.
Coupling gain, $G_{(dB)}$ Mobile-WSD reference geometry. We assume a median path gain of -56.15 dB, a DTT antenna gain of 9.15 dBi, a DTT antenna angular discrimination of -0.45 dB, and a DTT antenna polar discrimination of -3 dB. The resulting median coupling gain m_G is then equal to $-56.15+9.15-0.45-3 \approx -50.5$ dB. The coupling gain standard deviation σ_G is assumed to be 3.5 dB. Fixed-WSD reference geometry. We assume a median path gain of -54.72 dB, a DTT antenna gain of 9.15 dBi, a DTT antenna angular discrimination of 0 dB, and a DTT antenna polar discrimination of -16 dB. The resulting median coupling gain m_G is then equal to $-54.72+9.15-0-16 \approx -61.6$ dB. The coupling gain standard deviation σ_G is assumed to be 3.5 dB.

Table VII shows the resulting maximum permitted mobile-WSD in-block and out-of-block EIRP levels in the 9 pixels for a 16 MHz carrier-to-carrier separation between the mobile-WSD and the nearest-frequency DTT channel (N+2 adjacency). Here, we assume a maximum permitted decrease in location probability of 1%, a median coupling gain of -50.5 dB (mobile-WSD), a coupling loss standard deviation of 3.5 dB, an interference margin of 3 dB, a WSD ACLR of 36 dB, and a DTT receiver co-channel protection ratio of 16 dB. For $q_2 = 0.99$, we have $\mu(q_2) = 2.326$.

Note that the noise-limited environment means that $Z = P_S - U \approx P_S$. This will generally not be the case, and DTT self-interference, U, does affect the maximum permitted WSD emissions. As it happens, the most stringent emission requirements correspond to pixel 8. The maximum permitted in-block and out-of-block EIRP levels for the mobile-WSD in pixel 5 (centre pixel) may then be set to 15 dBm and -21 dBm, respectively.

Table VIII shows the resulting maximum permitted fixed-WSD in-block and out-of-block EIRP levels in the 9 pixels for a 16 MHz carrier-to-carrier separation between the fixed-WSD and the nearest-frequency DTT channel. Here, we assume a maximum permitted decrease in location probability of 1%, a median coupling loss of -61.6 dB (fixed-WSD), a coupling loss standard deviation of 3.5 dB, an interference margin of 3 dB, a WSD ACLR of 45 dB, and a DTT receiver co-channel protection ratio of 16 dB.

Again, the most stringent emission requirements correspond to pixel 8. The maximum permitted in-block and out-of-block EIRP levels for the fixed-WSD in pixel 5 (centre pixel) may then be set to 33 dBm and -11 dBm, respectively. Note that the relatively high in-block emissions levels are a result of the high quality of DTT coverage (i.e., high SINR) in the specific area examined.

V. CONCLUSION

In this paper we presented the types of detailed calculations which a geolocation database might perform in order to derive *location-specific* maximum permitted EIRP levels for white-space devices (WSDs) operating in digital terrestrial TV (DTT) bands. We introduced a novel methodology for the calculation of such EIRP levels, whereby the extent of protection of DTT protection is defined in terms of the maximum permitted degradation in the DTT *location probability*. We explained how the calculated EIRP levels need to be post-processed in order to derive consistent WSD regulatory emission limits for the simultaneous protection of multiple DTT channels. We also demonstrated, via numerical examples, that the resulting WSD regulatory emission limits can be quite high in areas where DTT coverage quality is good.

We have emphasized that, unlike for the case of *autonomous* WSDs, it is not necessary for regulatory bodies such as CEPT to define a fixed value for the maximum permitted EIRP of database-assisted WSDs. Flexibility should be afforded to national regulatory authorities who intend to authorize the use of database-assisted WSDs so that they can select the most appropriate parameters/algorithms according to their specific circumstances. We have noted that any harmful interference caused to DTT reception is a function of both the in-block and out-of-block emissions of the WSD. We have shown that the calculation of the

TABLE VI. OUTPUT OF THE DTT NETWORK PLANNING MODEL IN AN AREA WITH VERY GOOD DTT COVERAGE.

Pixel no.	Pixel coordinates		DTT wanted power, $P_{S\,(dBm)}$		DTT self-interference, $U_{(dBm)}$		DTT location probability, q_1
	Easting x (m)	Northing y (m)	Median $m_{S\,(dBm)}$	STD $\sigma_{S\,(dBm)}$	Median $m_{U\,(dBm)}$	STD $\sigma_{U\,(dBm)}$	
1	421700	200200	-34.56	5.50	-66.36	4.20	1.00
2	421800	200200	-34.46	5.50	-66.36	4.20	1.00
3	421900	200200	-34.46	5.50	-66.26	4.10	1.00
4	421700	200100	-34.46	5.50	-66.16	4.10	1.00
5	421800	200100	-34.36	5.50	-66.06	4.10	1.00
6	421900	200100	-36.86	5.50	-66.16	4.20	1.00
7	421700	200000	-34.46	5.50	-66.16	4.10	1.00
8	421800	200000	-36.96	5.50	-66.26	4.10	1.00
9	421900	200000	-36.86	5.50	-66.16	4.00	1.00

TABLE VII. OUTPUT OF THE GEOLOCATION DATABASE CALCULATIONS FOR MOBILE-WSDS AND A 16 MHZ CARRIER-TO-CARRIER SEPARATION FROM DTT.

Pixel no.	Pixel coordinates		$Z_{(dBm)}$ where $Z = P_S - U$		ACS(Δf) (dB)	$r(\Delta f)$ (dB)	WSD EIRP levels	
	Easting x (m)	Northing y (m)	Median $m_{Z\,(dBm)}$	STD $\sigma_{Z\,(dBm)}$			In-block $P_{IB\,(dBm)}$	Out-of-block $P_{OOB\,(dBm)}$
1	421700	200200	-34.55	5.53	45.65	-19.55	17.27	-18.73
2	421800	200200	-34.47	5.51	45.57	-19.54	17.40	-18.6
3	421900	200200	-34.48	5.49	45.57	-19.54	17.41	-18.59
4	421700	200100	-34.47	5.52	45.57	-19.54	17.37	-18.63
5	421800	200100	-34.37	5.52	45.49	-19.54	17.46	-18.54
6	421900	200100	-36.89	5.53	47.49	-19.70	15.09	-20.91
7	421700	200000	-34.49	5.50	45.57	-19.54	17.40	-18.6
8	421800	200000	-36.98	5.53	47.57	-19.71	15.01	-20.99
9	421900	200000	-36.87	5.51	47.49	-19.70	15.15	-20.85

TABLE VIII. OUTPUT OF THE GEOLOCATION DATABASE CALCULATIONS FOR FIXED-WSDS AND A 16 MHZ CARRIER-TO-CARRIER SEPARATION FROM DTT.

Pixel no.	Pixel coordinates		$Z_{(dBm)}$ where $Z = P_S - U$		ACS(Δf) (dB)	$r(\Delta f)$ (dB)	WSD EIRP levels	
	Easting x (m)	Northing y (m)	Median $m_{Z\,(dBm)}$	STD $\sigma_{Z\,(dBm)}$			In-block $P_{IB\,(dBm)}$	Out-of-block $P_{OOB\,(dBm)}$
1	421700	200200	-34.55	5.53	45.65	-26.30	35.12	-9.88
2	421800	200200	-34.47	5.51	45.57	-26.26	35.22	-9.78
3	421900	200200	-34.48	5.49	45.57	-26.26	35.23	-9.77
4	421700	200100	-34.47	5.52	45.57	-26.26	35.19	-9.81
5	421800	200100	-34.37	5.52	45.49	-26.23	35.25	-9.75
6	421900	200100	-36.89	5.53	47.49	-27.06	33.54	-11.46
7	421700	200000	-34.49	5.50	45.57	-26.26	35.22	-9.78
8	421800	200000	-36.98	5.53	47.57	-27.09	33.49	-11.51
9	421900	200000	-36.87	5.51	47.49	-27.06	33.60	-11.4

maximum permitted in-block EIRP level requires an assumption with regards to the spectral leakage of the WSD. For this reason, it would be helpful for the relevant technical standards organizations to specify a minimum required WSD adjacent channel leakage ratio (ACLR) for use in the calculations performed by geolocation databases. Otherwise the geolocation databases would need to be established based on an ACLR value that is only *representative* of the spectral leakage performance of WSDs. It is likely that the value of the ACLR would be underestimated in this situation, and result in over-stringent regulatory in-block EIRP limits.

APPENDIX

Currently, the growing consensus in the UK and in Europe is that the use of geolocation databases is the most promising, reliable, and flexible approach for allowing WSDs to access UHF TV bands. In this section, we explore some of the regulatory and standardisation issues which will

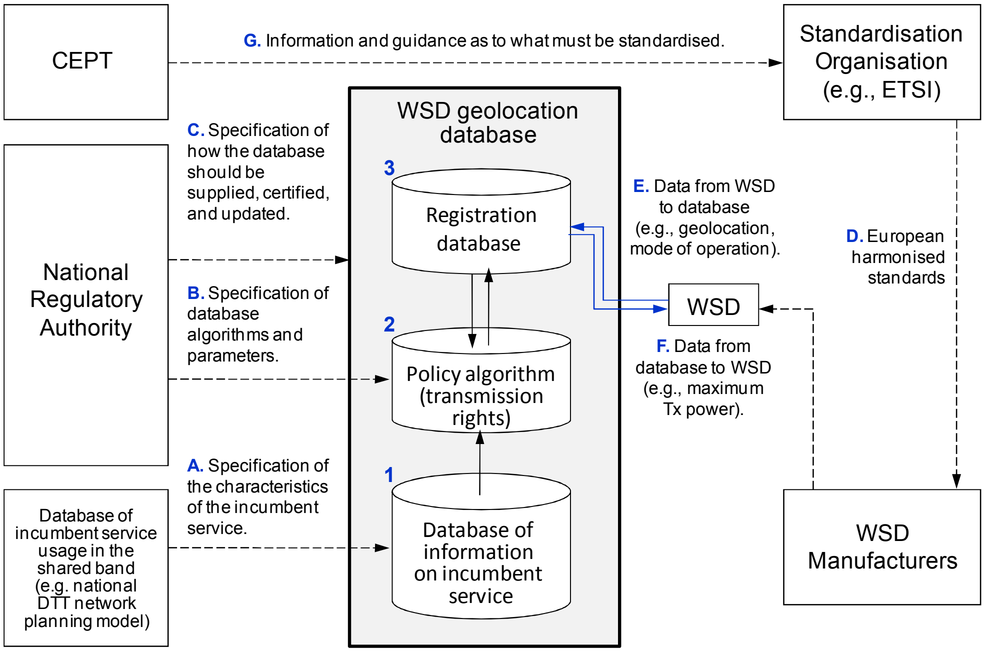

Figure 7. Illustration of the key entities involved in the regulation and standardisation of geolocation databases.

need to be addresses within Europe in order to facilitate the creation of such databases.

Figure 7 illustrates the interaction between the key players involved. These include the national regulatory authorities, the regulatory organisation CEPT, standardisation organisations such as ETSI, the database manager(s), the WSD manufacturers, and finally the WSDs themselves. Although Figure 7 has been produced with the WSD use of the DTT frequency band 470-790 MHz in mind, the general principles apply to all models of frequency sharing between WSDs and incumbent services.

The primary function of a geolocation database is to specify *location-specific* WSD transmission rights (e.g., in the form of maximum permitted EIRP) for the adequate protection of the incumbent service, and to deliver this information reliably to the WSDs. In order to derive the transmission rights, the geolocation database requires three distinct components. The first component is a database which contains information with regards to the use of the shared band by the incumbent service. In the context of the UHF DTT band, information on the incumbent services can be derived from the output of the national DTT network planning model (see A in Figure 7). The second component is a mathematical *policy* algorithm which computes the location-specific transmission rights of a WSD based on information regarding the incumbent service, the national regulator’s policies towards the protection of the incumbent service, as well as data with regards to the location and usage mode of the WSD. The details of such an algorithm were described in the main body of this paper. The third component of the geolocation database is what we refer to as a *registration* database. This is responsible for receiving information from the WSD with regards to the latter’s location and usage mode, and for delivering the calculated transmission rights back to the WSD.

Figure 7 also shows the responsibilities and activities associated with the regulatory and standardisation bodies that are critical for setting up a suitable regulatory framework to manage and update the flow of information to and from a geolocation database. The regulatory and standardisation linkages can be broadly grouped into two categories.

The first category consists of those activities that could be left to individual EU member state national administrations to develop independently. These include the following:

i) Specification of the characteristics of the incumbent service

Consider the example of DTT as the incumbent service in the shared band. Clearly the nature of the DTT network and the quality of the DTT service can vary significantly from one member state to another. Furthermore, member states have different legacy approaches for the modelling and planning of their DTT networks, and these models are developed and owned by different parties. As such, there is little room (and indeed little need) for a harmonised EU approach for the specification of the characteristics of the DTT service and the provision of this information to the different national geolocation databases. See A in Figure 7.

ii) Specification of the database algorithms

A geolocation database implements a number of algorithms as part of its operation. Perhaps the most important of these is the algorithm with which the database is able to calculate location-specific limits on the maximum permitted power radiated by the WSDs (see main body of this paper). Such limits are essential for the appropriate protection of the incumbent service. There is no reason why different national administrations should have to use the same algorithm, technical parameters, protection margins, or information regarding the incumbent service (even if recommended algorithms and parameters were made available by the CEPT). Indeed, it is more likely that depending on their specific policies and circumstances, different national administrations would wish to afford different levels of protection to the incumbent service, and so would prefer to use different algorithms, technical parameters, protection margins, and information regarding the incumbent service[8]. See B in Figure 7.

iii) Authorization regimes

National administrations should set up suitable WSD licensing regimes based on general or individual authorisation under the umbrella of the European Framework Directive. For example, a member state may decide to licence-exempt mobile/portable WSDs, but licence fixed WSDs if they radiate above a certain threshold. Although uniform decisions regarding the appropriate authorisation regimes among member states would be helpful, this would not be strictly necessary for the creation of a common market for equipment across Europe.

iv) Accreditation of databases

National administrations should establish a framework for the certification or accreditation of databases and their providers. See C in Figure 7. This is one of the key areas that needs to be investigated by the regulatory authorities, and could be a catalyst for delay in the introduction of databases.

The adequate protection of the incumbent services relies heavily on the accuracy of the information exchanged between the database and the WSD, as well as the accuracy of the information already contained in the database and the calculations performed therein. In order to provide necessary assurances regarding the above, suitable regulatory instruments and accreditation procedures will have to be developed by the national administrations. It may well be appropriate to develop guidance on this framework at a European level. However, this may prove to be a challenging task if diverse legal provisions already exist in this context in different member states.

The second category consists of regulatory and technical standardisation activities that should be undertaken in a harmonised manner across Europe. These activities are those that are essential for the creation of economies of scale primarily in the WSD market, and perhaps to a lesser degree, in the database provider market. These include the following:

v) Standardization of WSD radio characteristics

Within the EU, and under the provisions of the R&TTE Directive [7], member states notify the EC of the conditions of the radio interfaces that they regulate. Manufacturers[9] of radio equipment need to indicate conformity with the essential requirements of the R&TTE Directive[10]. Such conformity can be achieved through compliance with the relevant harmonized standards[11] or European Norms (ENs) normally developed by ETSI. These ENs include specifications of radio transmission (and sometimes receiver) characteristics, as well as descriptions of compliance test procedures. Such ENs will also be required for WSDs. See D in Figure 7.

vi) Standardization of interactions between WSD and database

WSDs are different from other radio equipment in one important way: they are required to perform a two-way exchange of information with a database prior to commencing radio transmission in the shared band. This exchange of information would also be covered under the provisions of the R&TTE Directive and would be subject to the same conformity procedures described above.

Examples of information exchanged from the WSD to the database might include an estimate of the location and speed (and a measure of their accuracy) of the WSD, and other information that can be used by the database to characterise the WSD's use; e.g., whether the WSD is fixed, portable, or mobile, operates indoor or outdoor, is a master or slave, or has any specific spectrum emission masks. See E in Figure 7.

Examples of information exchanged from the database to the WSD might include information on the identities of the available databases serving the geographic area of interest, location-specific regulatory limits on the maximum WSD radiated power, and the time duration over which the limits are valid (after which the WSD should again consult the database). See F in Figure 7.

While it is not necessary for the physical mechanism of the two-way exchange between the WSD and database to be specified, it is absolutely essential that the nature and format of the exchanged data, as well as the exchange protocol is standardised and made available (as embodied in a harmonised EN) to both WSD manufacturers and database providers. See D in Figure 7.

vii) Guidance from CEPT to ETSI

In view of the need for harmonised ENs described under items (v) and (vi) above, it is important for national regulatory authorities, under the umbrella of CEPT, to provide appropriate guidance to ETSI. See G in Figure 7. This is particularly the case since the radio characteristics of the WSD not only affect the cognitive radio link, but can also impact the operation of the geolocation database. For example, as described in the main body of this paper, if the technology standard specifies a WSD adjacent-channel leakage ratio that is too small (e.g., to allow low-cost devices), the database would inevitably calculate regulatory WSD in-block EIRP limits that are over-stringent (for a

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[8] There are strong parallels here with the diverse ways in which different European member states are dealing with the issue of interference from mobile networks in the cleared 790-862 MHz Digital Dividend band to the DTT services.

[9] Or persons responsible for placing the product on the market in the EU.

[10] Together with the essential requirements of all other applicable directives.

[11] Note that alternative methods of achieving conformity are also available under the provisions of the R&TTE. However, these are rarely used in practice.

specific level of protection of the incumbent service). The standards organisations must be made aware of such trade-offs.

Ofcom has recently published a consultation on the implementation of geolocation databases [2]. This presents proposals with regards to the nature of the data elements which need to be formalized by the regulators in order to facilitate the exchange of information between the geolocation database and the WSDs. These data elements should also form a basis for discussions within CEPT and ETSI with the aim of defining appropriate harmonized standards.

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