Technical Requirements for Portable TVWS Devices

Igor Gepko
Ukrainian State Centre of Radio Frequencies
Kiev, Ukraine
gepko@ucrf.gov.ua

Abstract—**To avoid the interference, there are large areas in TV planning called TV white spaces (TVWS) where certain channels are deliberately not used. It was proposed to use them for low-power wireless networking on non-interfering basis with the licensed (primary) Digital TV service. The lack of knowledge about locations of TV receivers as well as unreliability of the aggregate interference impact estimation caused by large number of White Space Devices (WSDs) accessing the spectrum are reported to be key challenges for the use of TVWS. We propose a novel approach where parameters required for protection of the primary system are calculated for a certain minimal separation distance observance of which for specific inhabited area could be ensured. In our view, to reuse spectrum efficiently the portable WSD has to support the dynamic power control via its sensing ability while the geolocation database which informs WSDs concerning the available channels should contain the list of recommended minimum distances.**

Keywords—TV white space; cognitive radio; white space device; spectrum sensing; secondary spectrum access; aggregate interference; LTE over TVWS.

I. Digital TV, "White" Spectrum, Cognitive Radio

To eliminate interference, the frequency reuse approach is followed in Digital TV planning similar to cellular network, avoiding the use of the same channel in two neighboring allotments. So, there are large areas where a specific channel is deliberately not used. These areas are called white spaces in television spectrum (TV white spaces: that is how they look at the coverage map). DTV allocations are very large compared to the size of cells in mobile communication, usually covering areas of several hundreds of square kilometers. Considering the economical value of TV spectrum and perfect propagation characteristics with reasonable size of antennas, it was proposed to use this "white" bandwidth for low-power low-range wireless networking on non-interfering (secondary) basis with the licensed (primary) DTV transmissions.

TVWS usage requires developing of mechanisms allowing to determine safely which TV channel could be occupied by the secondary device and what is maximum allowed effective isotropic radiated power (EIRP) that can be used. This is the idea of so-called *opportunistic* (secondary) spectrum access where mechanisms, employed by the network of such devices (White Space Devices, WSD) is a feature falling in a more general category of Cognitive Radio [1]. Two principal mechanisms were proposed there: spectrum sensing and geolocation. In the first, a node of secondary wireless network is equipped with the receiver periodically scans TV band searching for locally unused channels and estimating the signal level that could be permitted for its transmitter. Due to the static nature of locations and frequency assignments of licensed DTV transmitters one can create database containing a map of TV channels assigned to each location along with the power level allowable for WSD. Such a device determines its current location via built-in GPS receiver to find in the database set of channels with corresponding allowed power levels avoiding this way the interference with the primary users. Geolocation-based spectrum allocation can be applied simultaneously or together with the spectrum sensing. Thus, in the IEEE 802.22 regional cognitive radio access network standard channels allocation based on geolocation approach, while sensing also used to check if TV signal is present [2].

II. Problems of Deploying TVWS Radio Networks: The Protection of Primary Services

Licensed primary users must be reliably protected against potential secondary interference. At the same time restrictions imposed on secondary devices should not lead to a devaluation of white spectrum to the extent which makes secondary access useless. In the common cognitive-radio approach it is assumed that secondary device finds free spectrum by sensing signals of the primary users. However, in the literature low efficiency and poor spectrum-utilization performance of the spectrum sensing is alleged [3]. Among the major reasons of this are:

- Secondary device may miss to detect TV signals because of buildings or other surrounding obstructions even though TV channel is occupied (so called "hidden node problem").
- Not knowing the location of the primary receiver is a key problem due to high interference margin needed for protection of incumbent application. Detection of the primary system transmitter's signal by the secondary receiver does not provide reliable information regarding the propagation path between the secondary transmitter and the TV receiver, nor of the primary user's desired path gain.
- There is no reliable way for secondary device to assess the aggregate interference caused by large number of other WSDs accessing the spectrum: consequently the first one cannot determine its own maximum allowed transmission power.

According to [3] scanning has little sense in presence of the geolocation database which could indicate the occupancy of TV channels in the relevant geographical area in a much more-reliable way. At the same time, it's unlikely to expect the database containing certain information about the location of TV receivers. The statement was that the secondary reuse of TVWS is impractical unless the secondary user's transmitted powers (and the data rate) are extremely low [3]. Our view is such a conclusion is mainly predetermined by the interference scenario taken for analysis. The propagation loss between the primary transmitter and receiver was calculated [3] as

$$L_1 = L_{12} + (1-\beta)\cdot X_1,$$

where the constant $\beta \in \{0;1\}$ is a measure of the correlation between the observed level of primary signal on the input of sensing receiver and the same signal on the TV receiver input; L_{12} is a measured value of the path loss between the primary transmitter and the sensing receiver; and X_1 is a random value representing the uncertainty related to the unknown distance between the TV transmitter and TV receivers. Studies have been conducted for two boundary correlation values, for β=0 (where sensing does not make sense at all) and β=1 (where L_1 and L_{12} are related by deterministic way, i.e. the location of primary receiver is definitely known).

In this paper, our important assumption is the secondary device must not cause harmful interference to the TV receiver (with the typical TV antenna position) starting from a certain minimal separation distance which is ensured for the specific environment with the known terrain morphology

III. Interference Model and Secondary Access Scenario

Let us assume that the portable secondary device must not cause harmful interference to TV receiver starting from some minimal distance which is specific for this settlement. Assume next that the secondary device Tx2 knows the power P_1 of the primary transmitter Tx1, thus can perfectly estimate the path losses L_{12} between them (see Fig. 1). DVB-T external antennas assumed to be placed on the roofs (usually over the 10 meters heights) and have no directional properties with respect to secondary transmitters. The signal-to-interference ratio (SIR) in the primary receiver Rx1 is then (in dB)

$$SIR = S_1 - I_2 = P_1 - P_2 - L_1 + L_{21},$$

where $L_1 = L_{12} + X_1$ is the path loss prediction between the transmitter and the receiver of the primary system;

$$L_{21} = \overline{L}(r) - X_2 = \overline{L}(r_0) + 10n\log\left(r_1/r_0\right) - X_2 .$$

Here we use a simplified propagation model, where the mean loss in decibels follows the inverse n power law dependence of distance [3,4]. A log-normal random value X_2 with standard deviation from 6 dB to 10 dB (for TV band) [4] represents shadow-fading path loss component and $\overline{L}(r)$ is deterministic propagation path loss between the secondary transmitter and the primary receiver. Thus $SIR = P_1 - P_2 - L_{12} + \overline{L}(r) - X$, $X = X_1 + X_2$, wherefrom

$$P_2 + X = P_{Rx1} + \overline{L}(r) - SIR . \quad (1)$$

Let SIR be the minimal value of wanted-to-unwanted signal ratio at the primary receiver input, such that a desirable reception quality is achieved at the receiver output. For specified conditions (frequency offset), it will be a co-channel (adjacent channel, etc.) protection ratio. Then P_2 is the median value of secondary transmitter power which provides required SIR at the primary receiver input. The primary signal value measured at the input of the secondary receiver should be taken as a primary signal estimate at the input of the TV receiver (considering the typical antenna gain): $P_{Rx1} = P_1 - L_{12}$ [3]. This approach is based on assumption that primary signal levels at both receivers are nearly the same or strongly correlated.

It most cases however, primary signal is experiencing a greater attenuation at the WSD input than that for the fixed TV reception (where antenna location is specifically chosen). This result in underestimation of permissible power of the secondary transmitter. Indeed, DVB-T reception is usually done with the directive roof-top antenna which main lobe is looking away from the nearest omni-directional WSD transmit antenna. But the other situation may also happen when a secondary device is working somewhere on the upper floors of the building on the opposite side of a street. In this case, off-axis discrimination between the DTV receive antenna and the WSD transmit antenna is not ensured.

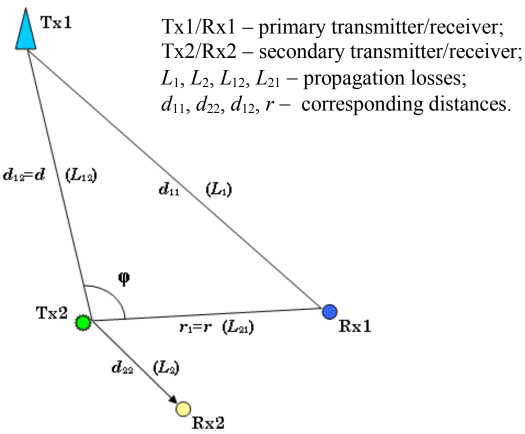

Fig. 1. The secondary use and interference scenario.

We assume that the secondary transmitter Tx2 which is the nearest to the TV receiver Rx1 (and which is located to the last one at a distance r_1) is the main interferer. In the following, we evaluate the aggregate interference caused by other WSDs. As there $d_{11}^2 = d_{12}^2 + r_1^2 - 2\cdot d_{12}\cdot r_1 \cdot \cos\varphi$, $\varphi \in [0; 2\pi]$, denoting $\Delta = d_{11} - d_{12}$ we have $\Delta(d_{11} + d_{12}) = r_1^2 - 2d_{12}r_1\cos\varphi$, so that $\Delta \approx \dfrac{r_1^2 - 2d_{12}r_1\cos\varphi}{2d_{12}} = \dfrac{r^2}{2d} - r\cos\varphi$. It follows $\mathrm{M}[\Delta] = \dfrac{r^2}{2d}$,

$$\sigma_\Delta^2 = \left\langle \left|\Delta - \mathrm{M}[\Delta]\right|^2 \right\rangle = \mathrm{M}\left[r^2\cdot\cos^2\varphi - \frac{r^3}{d}\cdot\cos\varphi\right] = \frac{r^2}{2} .$$

Since $X_1 = 10n\cdot\log\left(\dfrac{d+\Delta}{d}\right)$ and $\dfrac{\Delta}{d} < 1$, we get

$$X_1 = \frac{10\cdot n}{\ln(10)}\cdot\left(\frac{\Delta}{d} - \frac{\Delta^2}{2d^2} + \frac{\Delta^3}{3d^3} - \frac{\Delta^4}{4d^4} + \frac{\Delta^5}{5d^5} - \ldots\right) \quad (2)$$

Taking into account $\sigma_\Delta = r/\sqrt{2}$, $\Delta \approx r$ (that is, several tens of meters for the urban area [5]), and $d_1 \approx d_2$ (no less than $0.5 \div 1.5$ km from the TV tower, while $15 \div 50$ km is a typical DVB-T coverage range) we have $\frac{\Delta}{d} \le 10^{-2}$. Replacing Eq. (2) by the first term so that $X_1 = \frac{10 \cdot n}{\ln(10)} \cdot \frac{\Delta}{d}$, we have relative error which does not exceed a few percent of X_1 actual value. From aforementioned it follows

$$m_{X_1} = \frac{10nr^2}{2\ln(10)d^2} \approx 0 \text{ and } \sigma_{X_1} = \frac{10 \cdot n \cdot r}{\sqrt{2}\ln(10) \cdot d}.$$

Even at extremely large r (hundreds of meters) and minimal d (a few km), the mean square of X_1 will be about 1 dB. This value is much smaller in practice. For instance, if $d \approx 5$ km, r=50 m and n=4, we find $\sigma_{X_1} \approx 0.123$ dB. Therefore, X_1 is small compared to X_2. It follows that the uncertainty of the receiver location is unlikely be a critical factor for interference scenario selected for study. In this way we should consider the variable X to be normally distributed (in decibel) with the largest possible RMS within $\sigma_X = 9...12$ dB.

IV. Basic Relations and Results

The right hand side of Eq. (1) $P_L = P_{Rx1} - PR + \bar{L}(r)$ is a threshold which should not be exceeded in a certain percentage of the time (i.e., with a given probability Pr) for some median power P_2 of the secondary transmitter. Considering normal distribution of X we have

$$\Pr(P_2 + X \le P_L) = 1 - Q\left(\frac{P_L - P_2}{\sigma_X}\right),$$

where $Q(z) = \frac{1}{\sqrt{2\pi}} \int_z^{+\infty} \exp\left(-\frac{x^2}{2}\right) dx$. For instance, for 95 % of time $\frac{P_L - P_2}{\sigma_X} = Q_{5\%}^{-1} = 1.65$ (where Q^{-1} is the reverse meaning of the Q-function). From that it follows

$$P_2 = P_{Rx1} - PR + \bar{L}(r) - Q^{-1} \cdot \sigma_X . \quad (3)$$

The secondary device estimates the power of the TV signal as product of the effective aperture antenna and the average magnitude of the Poynting vector:

$$P_{Rx1} = \Pi \cdot S_{eff} \cdot G_A = G_A \cdot \frac{E^2}{120\pi} \cdot \frac{\lambda^2}{4\pi} = \frac{G_A}{480\pi^2} \cdot \lambda^2 \cdot E^2 .$$

Since the main lobe of DTV receive antenna is looking away from the omni-directional WSD transmit antenna, we assume 14 dB off-axis antenna discrimination [5]. In decibel notation (the field strength is expressed in dBμV/m, the power in dBm and frequency in MHz) one gets the following expression:

$$P_{Rx1} = E + G_A - 20 \cdot \log f - 10 \cdot \log \frac{160\pi^2}{3} - 50 . \quad (4)$$

Let the minimum rated distance r_0 is 10 m corresponding to free space loss of 50 dB at 800 MHz. Considering Eqs. (1), (3), (4) with [4] we obtain the estimation of the maximum allowed power for the secondary user

$$P_2 = E + G_A - 10\left(\log \frac{160(\pi f)^2}{3} - n \log \frac{r}{r_0}\right) - PR - Q^{-1} \cdot \sigma_X . \quad (5)$$

Distances which are needed for the protection of primary users (with the minimum median field strength 56 dBμV/m and DVB-T receiver antenna at the 10 m height) are presented in the Table I. Calculations have been made for two types of environment: high density urban area (n=4) and medium density urban / suburban area (n=3) [4]. Protection ratios for co-channel (N), adjacent (N+1) channel as well as N+2 channel interference were obtained by averaging corresponding values for DVB-T/DVB-T2 receivers provided in [6-9]. We also make a pessimistic assumption that secondary devices operate over the entire 8 MHz bandwidth of TV channel [1].

TABLE I.
Protection distances in meters: 99% TV service availability

channel (*PR*)	*n*	*EIRP of secondary transmitter*			
		40 mW	**100 mW**	**400 mW**	**1 W**
N (23 dB)*	3	2300	3200	5000	6800
	4	880	1120	1600	2000
N±1 (-30 dB)	3	70	90	150	200
	4	40	50	75	95
N±2 (-42 dB)	3	27	36	60	80
	4	15	18	27	33

* 64-QAM 3/4, fixed roof-level reception

From the Table I it follows that co-channel use requires protection distances from several hundreds of meters up to kilometers even with small power devices. Adjacent channel protection distances for WSD with power about 40 mW range from 40 up to 70 meters. This distance may be reduced to 20 – 27 m at the expense of less stringent requirements for primary receiver protection (95% service availability). We assume this to be a minimum distance between the DTV receive antenna and WSD transmit antenna required for urban environment.

The minimum median field strength (protected E_{min}) is the lowest field strength at the edge of the coverage area which permits achieving the required reception quality. For DVB-T, the variation range of E_{min} inside the protected contour is about 50 dB. Measurements show a log-normal distribution of DVB-T signal samples. The measured median value of received field strength is 63 dBμV/m [10], while ITU GE06 Agreement for Digital Broadcasting specifies 5.5 dB standard deviation inside large areas. These variations may be short-term and noticeable even during the one day time period depending on the changing weather conditions. Thus according to Eq. (5), the allowable power of a secondary transmitter is log-normally distributed.

Fig. 2 shows the probability density of P_2 for different types of environment (where low densities of TV-receivers in industrial districts assumed). For environments differing by housing density as well as by average building height (such as suburban and urban area), the difference in median permissible power is about 3 dB at the distance 20 m between the WSD and TV receiver (curves 1 and 2) and up to 7 dB at the 50 m distance. Reducing separation distance between WSD and TV receiver from 50 m to 20 m decreases the permissible power of secondary transmitter by 16 dB. In contrast with that, reducing the requirements for primary receiver protection (from 99% to 95% service availability) increases the permitted power of the WSD for 8 dB.

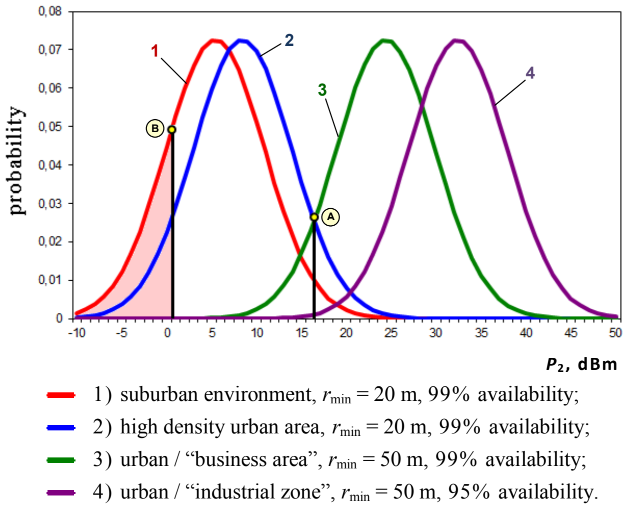

Fig. 2. Permissible power of secondary transmitters.

The U.S. Federal Communications Commission (FCC) has allowed portable WSDs to operate on adjacent channels within the DTV protected contour only if their maximum conducted output power does not exceed 40 mW (the protection ratio is assumed to be –33 dB) [5]. But in densely populated areas with a large number of households even the WSD with the power of 40 mW is a potential source of interference for most of receivers. Fig. 2 shows that the 16 dBm value exceeds at least 96% of WSD power levels permitted for a certain location (marked by "A"). On the other hand, in a sparsely populated or non-residential area (say hotspots in a business center) even being located at a greater distance from the victim receiver (r_{min}=50 m, curve 3) portable device operates with the power 10 dB less than the median permissible value, underutilizing that way the available spectrum resource.

Thus, WSD operation in a fixed power mode is far from the optimal. However evaluation of P_2 without sensing based on some propagation pattern is unlikely to provide a better result. Thus according to Eq. (5) P_2≈0 dBm for E=56 dBμV/m (Fig. 2, "B"). In this case, about 1/6 of the WSDs operate with power exceeding the recommended level and the other operates with the power less of this value. So the available spectrum resource is underused in terms of coverage and the data rate.

To use spectrum efficiently, mobile/portable WSDs should have dynamic power control facility. The geolocation approach is unlikely to be an effective solution since the minimum distance between the WSD and the victim TV receiver is much smaller of the typical pixel size (100×100 m ÷ 250×250 m). Measurements made by some special receiver within the pixel will not be correlated sufficiently with the primary signal on the TV receiver input. Spectrum sensing seems to be the best source of data about the local electromagnetic environment. By estimating the median power of the primary signal at the input of potentially nearest TV receiver, secondary device evaluates the allowable EIRP of its transmitter thereby implementing the Open Loop Power Control scheme in the secondary system.

V. Evaluation of Aggregated Interference Effect

Secondary access is commercially attractive only when it is scalable and supports a sufficient amount of secondary traffic in a large area. This means that the primary spectrum is reused by multiple secondary users. A method to regulate transmission powers of secondary users in TV white spaces is proposed in [11]. In brief, the main idea is to divide a service zone into pixels where the maximum allowed transmission power for a secondary user is calculated with the constraint of the TV coverage probability as follows:

$$\Pr\left[PX_P \geq PX_{P,\min} + I_{TV} + I(P_{S,\max}) + IM\right] \geq q\,.$$

In this, q is the required TV-coverage probability, PX_P is the power of primary signal at the input of TV receiver, $PX_{P\min}$ – the minimum TV-receiver sensitivity, I_{TV} – interference from other TV transmitters and $I(P_{S,\max})$ – the interference from the secondary user as a function of $P_{S,\max}$. Here the safety margin and multi-user margin are accounted by the term IM. However there are still no unified guidelines for its obtaining [3]. A conservative value of IM results in poor spectrum utilization, while insufficient multi-user margin leads to a risk of failing TV receiver's protection.

Let $P_{\text{Rx}1}^{(1)} = P_2 - 10n\log r_1$ be a median power of signal from the nearest WSD measured at the input of TV receiver. The interference terms from other WSDs:

$$P_{\text{Rx}1}^{(2)} = P_2 - 10n\log r_2\,;\ \ldots\,;\ P_{\text{Rx}1}^{(k)} = P_2 - 10n\log r_k\,.$$

Here we considered an example scenario 1 (fig. 3) where secondary devices are located at distances r_1=r; r_2=$2r$; … r_k=$k\cdot r$ from the TV receiver (so that $P_{\text{Rx}1}^{(k)} = \frac{1}{k^n}\cdot\frac{P_2}{r^n} = \frac{1}{k^n}\cdot P_{\text{Rx}1}^{(1)}$ for the linear scale). Thus the aggregate interference power $I_\Sigma = \sum_{k=1}^{\infty} P_{\text{Rx}1}^{(k)} = P_{\text{Rx}1}^{(1)}\cdot\sum_{k=1}^{\infty}\frac{1}{k^n}$ is expressed by the sum known as Riemann zeta function [12]:

$$\sum_{k=1}^{\infty}\frac{1}{k^n} = 1 + \frac{1}{2^n} + \frac{1}{3^n} + \ldots = \zeta(n)\ \text{(where } n>1\text{)},\ I_\Sigma = P_{\text{Rx}1}^{(1)}\cdot\zeta(n)\,.$$

According to Euler, the values of the Riemann zeta function at even positive integers are expressed in terms of Bernoulli numbers [12] which can be found from the recurrence relation

$$\zeta(2k) = (-1)^{k+1}\frac{(2\pi)^{2k}}{2(2k)!}B_{2k}\,,\quad \sum_{j=0}^{k}\binom{k+1}{j}B_j = 0,\ k\geq 1\,. \tag{6}$$

As it follows from Eq. (6), B_0=1, B_1=–1/2. The value of ζ(3) is known as Apéry's constant [13], and ζ(5) is published in [14].

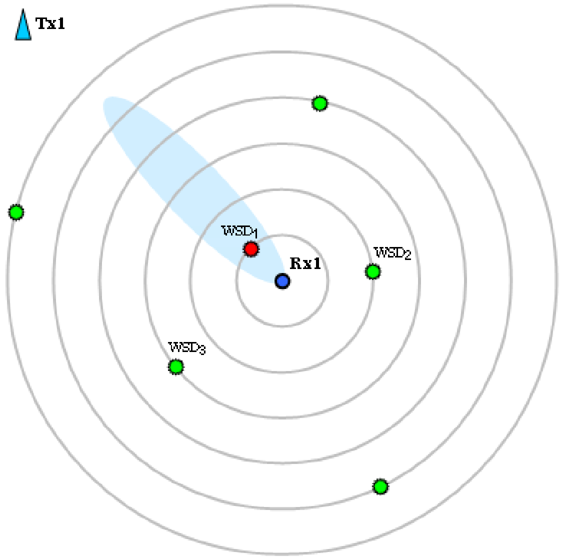

Fig. 3. Aggregate interference scenario 1.

Let r_k^2 be a total number of secondary users within a range of distances [0; r_k] from the TV receiver (the scenario implies the density $\frac{1}{\pi \cdot r_1^2}$ of active WSDs about 127 devices per 1 km² for r_1=50 m which much exceeds densities of IMT terminals used for compatibility studies [15] in the frequency band 790 – 862 MHz). At the range $r \approx r_k$ this number is about $r_k^2 - r_{k-1}^2$, so $I_\Sigma = P_{\text{Rx}1}^{(1)} \cdot \sum_{k=1}^{\infty} \frac{k^2 - (k-1)^2}{k^n} = P_{\text{Rx}1}^{(1)} \left(2\zeta(n-1) - \zeta(n)\right)$, so for accounting the impact of aggregate interference an additional safety margin of 3 dB or less is needed.

Table II shows how this impact depends on propagation environment. It should not be neglected for slowly attenuating path loss open areas e.g., rural or suburban. But for medium with the rapid attenuation (n=4÷5) this effect is not significant so using multi-user margin may not be necessary. Table III shows dependence of allowed WSD power from the distance between the TV receiver and the nearest secondary device.

TABLE II.
THE IMPACT OF THE AGGREGATE INTERFERENCE VERSUS n

n	3	4	5	6
$2\zeta(n-1) - \zeta(n)$	2.087818	1.321776	1.127726	1.056496

As the reference medium here we considered high-density (n=4) urban environment with the maximum shadow-fading standard deviation σ=12 as well as low-rise buildings / suburbs (n=3, σ=9). Assuming 20 meters to be a minimum distance between the WSD and TV receiver, we see that the aggregate interference impacts the allowed power of WSD in a way that it becomes smaller than that of rated 40 mW value [5].

TABLE III.
THE MAXIMUM ALLOWED TRANSMISSION POWER FOR CHANNEL N±1

Surroundings	%	*minimum safety distance between the WSD and DTV*			
		20 m	**30 m**	**40 m**	**50 m**
Urban area	95%	33 mW	170 mW	0.5 W	1.2 W
	99%	5 mW	25 mW	85 mW	200 mW
Suburbs	95%	33 mW	100 mW	250 mW	450 mW
	99%	8 mW	25 mW	65 mW	130 mW

VI. THE TECHNICAL CONFIGURATION OF WSDS

Even in case of mass deployment, for a long period WSD will unlikely be a cheapest device which nevertheless provides services highly localized in time and space. License-exempt networking contributes in reducing the cost of services but unlikely be a compensation of above shortcoming from the consumer point of view. Sales of WSDs as individual devices will hardly allow their manufacturers to benefit from the economies of scale in a reasonable term. That is why the implementation of WSD as a special module of 3G/4G user equipment is the possibility to ensure its market success. In such alliance, white space device obtains free GPS facility and the independent wireless channel connecting it to a geolocation database with the channel tables while smartphone acquires a supplementary frequency band with perfect propagation characteristics.

The key issue to be solved via access to the geolocation database is to provide the secondary device with a consistent list of protected services (and locally available channels) for a given location. This information can be updated via the main portable equipment wireless interface with the periodicity of a weather forecast. The database could contain recommended parameters for calculations of the path loss (taking into account the actual terrain morphology) as well as rated minimum safety distances associated with the each location. Both these sort of data should be specified in-service gradually after the introduction of cognitive network into operation.

White space devices should operate at variable power levels using the lower power in areas of poor availability of the TV services. The key task of cognitive spectrum sensing has to be power control, where each portable device is responsible for calculation of its allowed transmission power. The power control scheme will operate based on the estimate of median value of the primary signal at the WSD receiver input using the recommended safety distance for current location. Hidden terminal problem will never occur with this approach. If there exists a reliable data source (a geolocation database) indicating that the channel is used, a low (or even undetectable) level of signal at the input of WSD informs it regarding the adverse reception conditions for the nearest TV receiver. This permits for the secondary device safely evaluate its maximum allowed transmission power.

Long Term Evolution (LTE) with its flexible deployment in terms of bandwidth is a nice platform for implementation of the WSD physical layer. Combined terminals in particular will extend the LTE operational mode over the digital dividend I/II bands (790 – 862 MHz / 694 – 790 MHz) both on the primary as well as the secondary basis. After the expected allocation of digital dividend II to mobile service at the World Radio Conference-2015 (WRC-2015) equipment capable to change its operational mode will provide flexibility regarding the coordination procedures in border areas for neighboring countries following different priorities in the use of spectrum.

Sharing of spectrum is effective if the requirements for the use of spectrum of primary system differ sufficiently from the usage pattern of the secondary system. The secondary systems should also have accurate information about technical features and usage pattern of the primary system (including location of transmitters, local relief and relevant propagation losses). This is unrealistic with respect to wireless microphones, video cameras and program making and special events equipment due to liberalized nature of their application. So some administrations see a solution in the localizing their operation within one or two TV channels. In particular, the Office of communications of the United Kingdom (Ofcom) has licensed the channel 38 for exclusive access by the Programme Making and Special Events (PMSE) equipment. In case it does appear to be not sufficient for large events with several dozen microphones in use, primary users could operate other channels as well. These devices are registered in a database on a temporary basis. Periodically WSD interrogates the database to find out which channels are free (updates will be typically every 2 hours) [16].

VII. Conclusion

The study presented in this paper unveils the necessity for revising the functions associated with sensing and geolocation abilities in the TVWS cognitive radio system. The key role of spectrum sensing is to implement a power control scheme, whereby portable device evaluates its allowed transmission power. The geolocation database should provide the WSD with the list of locally available channels, parameters for path loss calculations for the local terrain morphology as well as with the recommended values of minimum safety distances associated with given locations. WSD should operate at variable power levels using the lower power in areas of poor availability of the TV services. To reuse spectrum efficiently, the portable secondary device has to support the dynamic power control via its sensing ability.

In this paper, we propose a novel approach where parameters required for protection of the primary system are calculated for a certain minimal separation distance observance of which for specific inhabited area could be ensured. According to our estimates, in this scenario the uncertainty of the receiver location does not limit dramatically the accuracy of the power margin needed for TV protection.

Optimization of spectrum sharing implies differences in usage patterns of the primary and secondary systems. The last one should have accurate information about the technical features of the primary system, including local relief, location of transmitters and building characteristics. This is unrealistic with respect to PMSE devices due to liberalized nature of their application. Thus it is advisable to ensure their interference-free operation by localizing this equipment within one or two channels exclusively allocated to them.

We do not expect that the sales of WSDs as the separate devices will allow the manufacturers to benefit from the economies of scale in a reasonable term so the implementation of WSD as a module of the 3G/4G cellular user equipment is an attractive market solution. LTE equipment which is able to operate both on the primary and secondary basis can provide the flexibility of the spectrum usage after the allocation of the digital dividend II band to the mobile service at the WRC-2015.

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