DTV protection regions for spectrum sharing

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Abstract: In this Letter, the authors propose a technique that allows a secondary user (SU) to reuse the spectrum allocated to TV broadcast system. The approach is based on protection view point and an SU is allowed to transmit outside the noise limited contour (grade B contour) with additional protection margin. An algorithm was developed that predicts the grade B contour and makes a decision on the availability of the spectrum. The keep-out distance was obtained using the existing path loss models and a model developed based on field strength measurements conducted in the very high frequency (VHF) and ultra high frequency (UHF) broadcast frequencies. Results of simulation indicate that the extra margin does not follow a linear curve as expected, but strongly depends on the operating frequency and terrain profile of the area. In addition, the measured model's prediction deviates significantly from the other models' prediction.

1 Introduction

With the exponential demand for wireless data service, the next generation cellular systems would face challenges. This calls for a technique that would allow the use of the unused portion of the spectrum allocated to TV broadcast, also known as TV white space (TVWS), on a non-interfering basis. One major factor that would facilitate the exploitation of this TVWS is the proper planning of the primary users (PUs) and deployment mechanism for the secondary users (SUs) to ensure peaceful coexistence. Two major strategies for identifying TVWS were proposed; the sensing and the geo-location database. In the latter, SUs are allowed co-channel reuse of the TV spectrum at the so called keep-out distance [1, 2] to guarantee non-interference and is considered as an immediate solution by the regulators. Several studies have sought to maximise the available TVWS for SUs in accordance with the regulatory guidance on interference. Kang *et al.* [1] presented experimental and simulation results for the use of secondary networks in TVWS. In that paper, the concept of keep-out distance of SUs from the digital television (DTV) protected contour was obtained using the Okumura, ITU-R 1546, Federal Communication Commission (FCC) and measurements of UHF signals in Korea. Other studies are presented in [3–6]. Most of the studies presented do not account for the impact of path loss model and system parameters such as the detection threshold, regulators rules, transmit power, frequency and heights of the keep-out distance on the availability of white space. In this Letter, we develop a model that allows the SU to spatially reuse the PU frequency without causing unwanted interference. The impact of the system parameters and terrain on the co-channel keep-out distance was also investigated.

2 System model

The model considered in this Letter is a system where the primary transmitter communicates with primary receivers within the noise limited contour [7], that is, the protection area of the primary cell. The SU can reuse the same frequency near the cell border of the PU if it meets the required condition specified by FCC for white space. The grade B contours, that is, where received signal strength for channels 14 through 69 exceeds 64 and 41 dBu for analog and digital TV systems, respectively [8]. These contours were calculated in accordance with the specific procedure described in Sections 73.622 and 73.625 of the FCC Rules and Regulations [9]. Let r_{p} represent the protection contour and r_n be the no-talk radius. Outside, there exist safe-to-transmit regions given by $r_n \subset \Re^3$, in which a co-located transceiver can operate on the same frequency band. A white space in space-time is defined as an indicator function 1_D: $\Re^3 \rightarrow \{0, 1\}$ given by

$$1_D(x, f, t) = \begin{cases} 0, & \text{if } x \in r_n \\ 1, & \text{if } x \in \Re^3 \backslash r_n \end{cases} \tag{1}$$

where x is a coordinate in space where a secondary transmitter may or may not transmit, f is the frequency and t is the time. The protection region r_{p} is the service area (i.e. noise limited grade B contour) for a given primary transmitter as shown in Fig. 1. The maximum coverage distance, r, is the distance where the received signal level (in dBu) is greater than or equal to the minimum signal level, λ, at the grade B contour as defined by FCC [9].

For full digital TV in the UHF (14–69), the protected contour E-field is 41 dBu and the co-channel interference protection ratio D/U is 23 dB. The received signal level P_{r} is given by

$$P_{\mathrm{r}} = P_T + G - \Psi(r) - N_0 - l(r_{\mathrm{p}}) \geq \lambda \tag{2}$$

where G is the gain of the antenna (in dBi), N_o is the thermal noise level (in dBm) and $l(r_{\mathrm{p}})$ is the path loss. Therefore the range of the

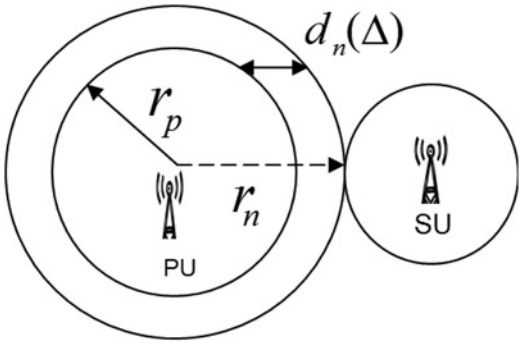


Fig. 1 *DTV protection contour and no-talk margins*

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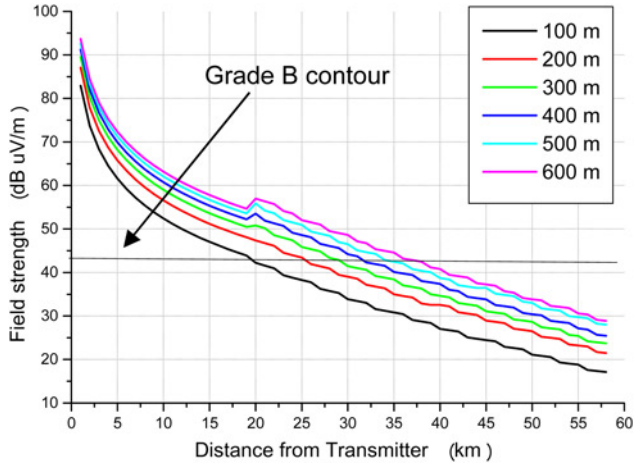


Fig. 2 *Variation of field strength with distance for KWTV 583.25 MHz transmitting at 1 kW at different heights*

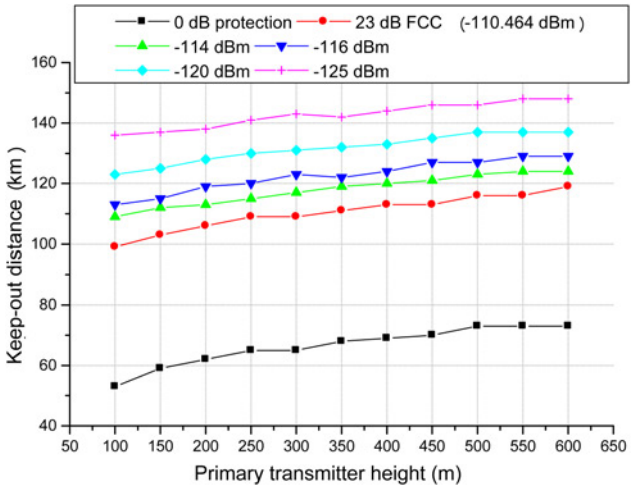


Fig. 4 *Keep-out distance for different protection levels for 100 kW CH 21 TV transmitter*

protection contour is derived as follows

$$r_{\mathrm{p}} = l_{\mathrm{p}}^{-1}(P_T + G - \Psi(r) - N_0 - \lambda) \tag{3}$$

where $\Psi(r)$ is the fade margin. The keep-out distance is derived as

$$r_n(\lambda,\ p_T,\ h_t,\ \Delta) = r_{\mathrm{p}}(\lambda,\ p_{_T},\ h_t) + d_n(\Delta) \tag{4}$$

$$d_n(\Delta) = l_{\mathrm{p}}^{-1}(P_T + G - \Psi(r) - N_0 - \lambda + \Delta_i) \tag{5}$$

where $r_{\mathrm{p}}(\lambda, p_T, h_T)$ is the protection radius and $d_n(\Delta)$ is the additional protection distance that depends on the protection margin Δ_i.

3 Field strength measurements

Our earlier studies in [2, 10] have demonstrated the importance of using an appropriate propagation model in signal prediction. In this Letter, large-scale field strength measurements in the VHF and UHF frequencies along six different routes that spanned through the urban, suburban and rural areas in Kwara state, Nigeria were conducted using a dedicated Agilent spectrum analyser, N9342C (100 Hz–7 GHz) with a displayed average noise level of −164 dBm/Hz. Total route length and number of points were 109 km and 286, 870 data samples, respectively.

4 Simulation results

Fig. 2 shows the variation of field strength with distance for Kwara State TV (KWTV) station operating on channel (CH) 35, that is, 583.25 MHz and 1 kW power as function of height. The International Telecommunication Union (ITU) regulation of 41 dBu for service contour for digital TV systems is considered.

The co-channel keep-out distance with and without interference protection margin for 1 kW CH 21 TV transmitter was estimated and the additional protection distance, $d_n(\Delta_i)$ was obtained as a function of height of the transmitting antenna. The result is shown in Fig. 3. In this scenario, the interference protection margin Δ of 23 dB was used. The result shows significant impact of terrain and frequency on the protection distance.

The impact of regulator protection threshold on the co-channel keep-out distance was investigated, and the result is shown in Fig. 4. From our analysis, the FCC's −114 dBm provides an extra 3.5 dB protection to the original 23 dB protection margin proposed for primary transmitter, and Ofcom's −116 dBm sensing threshold is found to be highly conservative as it provides an additional margin of 5.5 dB. Fig. 5 shows the terrain impact on grade B contour as a function of PU height for both the measured path loss and other established models. The result shows significant deviation of the measured path loss when compared with the conventional models. Fig. 6 shows spatial interpolation of available UHF channels. This was achieved through geographical information system

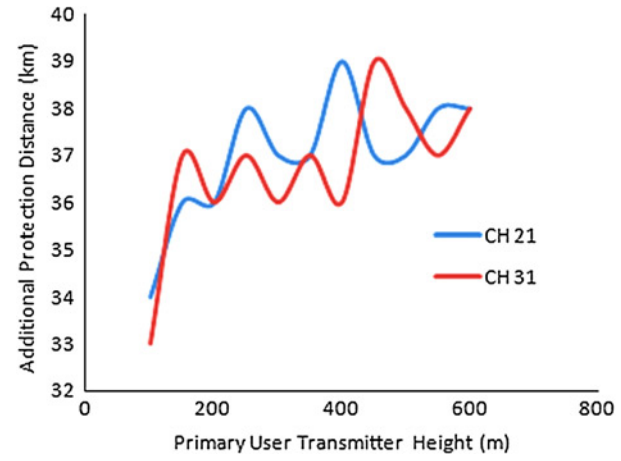


Fig. 3 *Terrain impact on protection margin as a function of operating frequency*

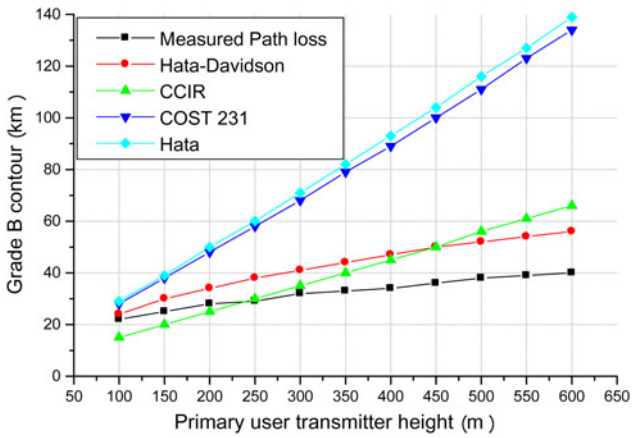


Fig. 5 *Terrain impact on grade B contour for empirical models*

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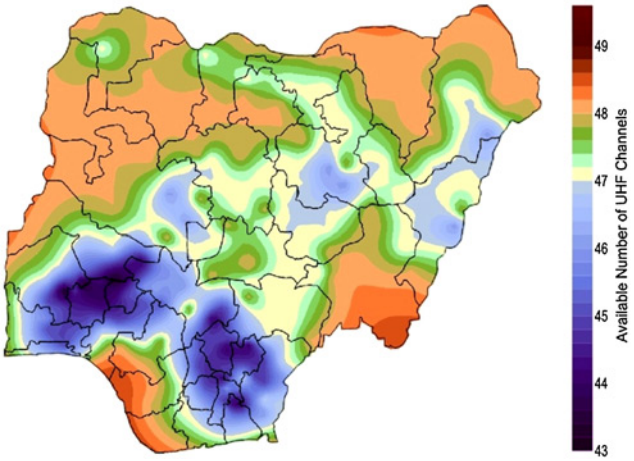


Fig. 6 *Spatial interpolation of available UHF channels in Nigeria*

(GIS) buffering operation within the spatial analyst tool of ArcGIS extension tools and surfer software application package. The spatial data used include the administrative map of Nigeria showing the state boundary delineations, which was acquired from the Regional Center for Training in Aerospace Surveys (RECTAS), Ile-Ife, Nigeria. The transmission and protection contour of each transmitter were obtained using (3) and (4).

5 Conclusion

In this Letter, we provide a spectrum sharing model for TV band. Results of our finding indicate that regulators would have to create a tradeoff between PU protection and maximising the available white space, particularly close to the border of the PU cell. In addition, the least protection margin that would guarantee maximum protection for lower primary network should be at least 23 km, which is far above the 14.4 km co-channel separation distance proposed by FCC.

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