TV White Spaces Maps Computation through Interference Analysis

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Abstract: For the characterization of TV White Spaces (TVWS), an extensive simulation of the impact of interfering signals was undertaken in a generalized scenario. The simulation for these investigations was derived from a Monte Carlo methodology using SEAMCAT, and the results include the computation of TVWS maps as it can be done with the access to a geo-location database, or based on autonomous sensing only. Geo-location database approach is shown to utilize TVWS spectrum more efficiently. The impact of Professional Wireless Microphone Systems (PWMS) devices on the availability of TVWS is also analyzed and imposes additional limitations of the maximum power emitted by secondary spectrum users.

Keywords: TVWS, Co-existence analysis, Co-channel interference, Adjacent-channel interference, Geolocation database, Autonomous sensing.

1. Introduction

CEPT defines the term “White Space” in report 24 [1] as “a label indicating a part of the spectrum, which is available for a radio communication application at a given time in a given geographical area on a non-interfering / non-protected basis with regard to other services with a higher priority on a national basis.” Hence, the amount of available white spaces in the band 470-790 MHz, which consists of UHF channels 21-60, depends on incumbent services namely, Digital Video Broadcasting – Terrestrial (DVB-T) and Professional Wireless Microphone System (PWMS).

The objective of this paper is to derive TVWS maps from interference simulations, between incumbent systems (DVB-T or PWMS) and a Secondary Communication Network (SCN). Section 2 describes the methodology used for TVWS maps computation. Section 3 presents parameter values and examined scenarios. Section 4 follows with simulation results using two acquisition mechanisms: geo-location database and autonomous sensing. We also investigated the impact of PWMS activity on the availability of TVWS. Conclusions are finally drawn in Section 5.

2. Methodology for the Derivation of the Probability of Interference

TVWS characterization can be done based on exhaustive measurements campaigns, or based on simulation. For the second choice, the use of a Monte Carlo technique can address any of the radio interference scenarios regardless of the interfering and incumbent systems. SEAMCAT - Spectrum Engineering Advanced Monte Carlo Analysis Tool from CEPT is used to study the interference between primary and secondary users. The meaning of probability of interference and the details of the interference computation method used in SEAMCAT are given in [2]. While TVWS devices technology is still unknown, 3GPP Long Term Evolution (LTE) standard [3] operating over TVWS is used as proxy for a SCN.

2.1 – Interference computation

Two methods are used to compute the maximum allowed power, for the interfering transmitter to avoid causing harmful interference. In the following, a short description of both is provided.

- Geo-location database approach

This approach assumes that the location of the interfering system is known together with the transmitter and receiver parameters. For each location, the interfering power is swept to find the maximum power admissible to keep the probability of interference below a predefined threshold. A Monte Carlo simulation is carried out, and results are saved to produce a map with the maximum allowable power that can be used by a secondary transmitter. This process, if repeated for each DVB-T channel, results in a spectrum pool for a given area.

- Autonomous sensing approach

At each pixel, a BS or UE with spectrum sensing capabilities conducts a measurement within a candidate channel to determine whether any protected service is present and transmitting. When a channel is determined to be vacant, sensing is applied to adjacent channel to identify if there is any constraint on transmission power. If the cognitive device detects no emission above this threshold in a channel, the secondary user is allowed to transmit; otherwise it keeps silent or looks into other channels.

3. Simulation Scenarios

In this section we present interference scenarios between a SCN link and two incumbent systems, DVB-T and PWMS. Unless otherwise stated, all parameters values are as described in subsection 3.3 below.

3.1 DVB-T and SCN geometries

Figure 1 illustrates the interfering and the DVB-T deployment geometries considered in this study. The interfering SCN is modeled as a single link between a Base Station (BS) and User Equipment (UE). The impact of the interference caused by a BS or a UE is evaluated for the case of a victim DVB-T receiver, located at the coverage edge of a DVB-T cell, which corresponds to a worst-case scenario.

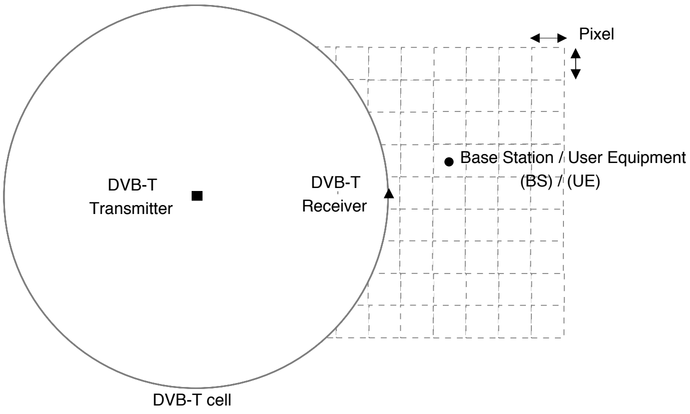

Figure 1 DVB-T and SCN deployment scenario.

The area surrounding the DVB-T cell is subdivided into pixels, using a grid with rectangular coordinates (x,y). The proposed method assumes that the interfering system is not allowed to transmit inside the coverage area of the DVB-T transmitter. The axis origin (0,0) is located at the TV receiver position. The interfering transmitter is then placed in the center of each pixel. Figure 2 shows a more detailed view of the various radio links. The

DVB-T receiver antenna is considered to be always directed towards the azimuth and elevation bearings of the broadcast tower (BT). The wall blocks the UE from attempting to detect the BT signal. However, BS is not affected since they are above rooftop level.

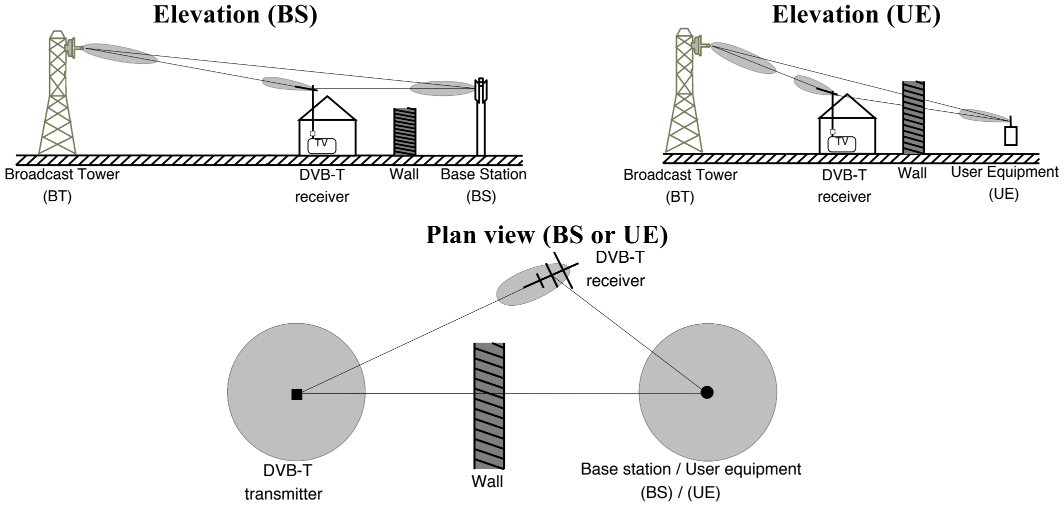

Figure 2 Geometry of the SCN (BS and UE) – DVB-T (interference) links.

3.2 PWMS and SCN geometries

The scenario depicted in Figure 3 describes a PWMS link located in an urban environment, where a wireless microphone link is located inside a building. The interference study is conducted with a UE transmitter, located in three different places: inside the same room as the PWMS link, outside the building and inside another building.

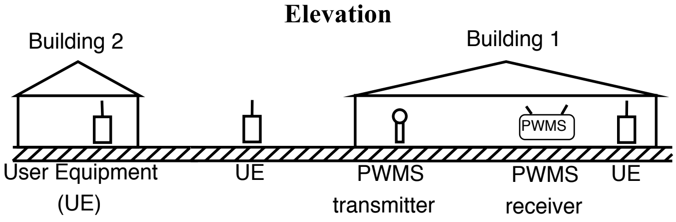

Figure 3 Geometry of the SCN – PWMS (interference) links.

3.3 Parameter values

Simulations are performed (at 658 MHz) with the mean path-loss based on the Extended Hata model for distances up to 50 km, and the ITU-R 1546 model for separations greater than 50 km. An exception is made for PWMS links, which are simulated using an extended Hata SRD propagation model. This is a modified version of the SE41 Hata model used by the SE24 study group for study of short-range devices, and valid for distances up to 300 m. A lognormal shadowing is also assumed, with a standard deviation of 3.5 dB for distances up to 40 m, and values ranging from 5.5 dB to 17 dB for greater separations, depending on the propagation mode (below or above rooftop). A lognormal wall loss was also considered where appropriate, with a mean value of 5 dB and a standard deviation of 5.5 dB. All separations refer to horizontal distances.

For the DVB-T broadcast tower, UE transmitter and PWMS receiver, antenna patterns were assumed to be omnidirectional in azimuth and elevation. The DVB-T receiver antenna was based on recommendation ITU-R BT.419-3. For BS towers, we used three 120º sectored antennas. Handheld wireless microphones are equipped usually with $\lambda/2$ or $\lambda/4$ dipoles, so their radiation pattern is directional in elevation. These antenna patterns are illustrated in Figure 4.

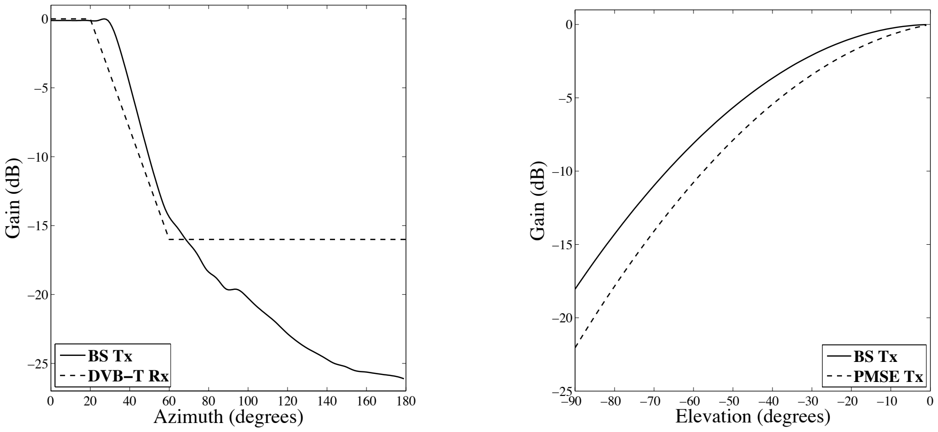

Figure 4 Antennas gain and pattern.

Spectral emission mask for BS and UE are illustrated in Figure 5. The emission mask of UE is based on 3GPP standard [3] that defines the maximum Out-of- Band (OoB) emission limits for UE. For BS, the spectrum mask suggested by CEPT in Report 30 is considered. DVB-T and wireless microphone emission masks are adapted from CEPT report 104 and ETSI technical report [5], respectively.

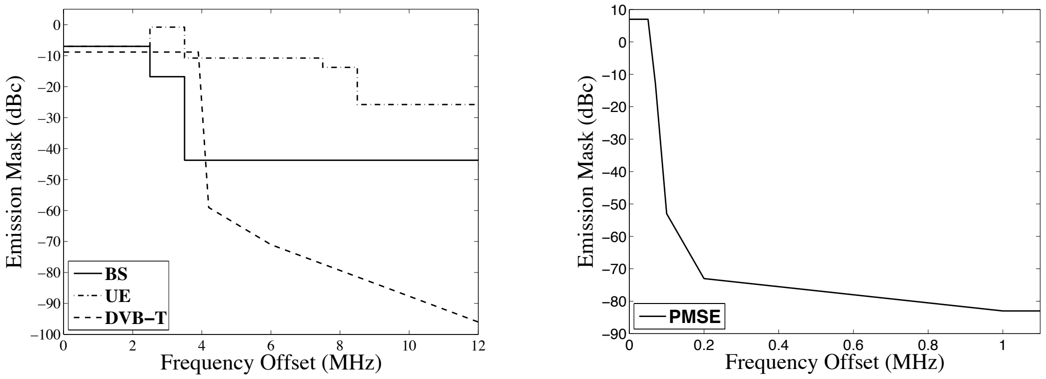

Figure 5 Transmitters emission masks normalized in 1 MHz measurement bandwidth.

The frequency selectivity of the DVB-T receiver was modeled according to the protection ratio (PR) values in Figure 6 a). These values are extracted from measurements [4] of PR for a DVB-T receiver in the presence of an adjacent-channel DVB-T interferer using LTE technology. Results are presented as the ratio of maximum acceptable level of interfering signal to the wanted signal level, at a given frequency separation.

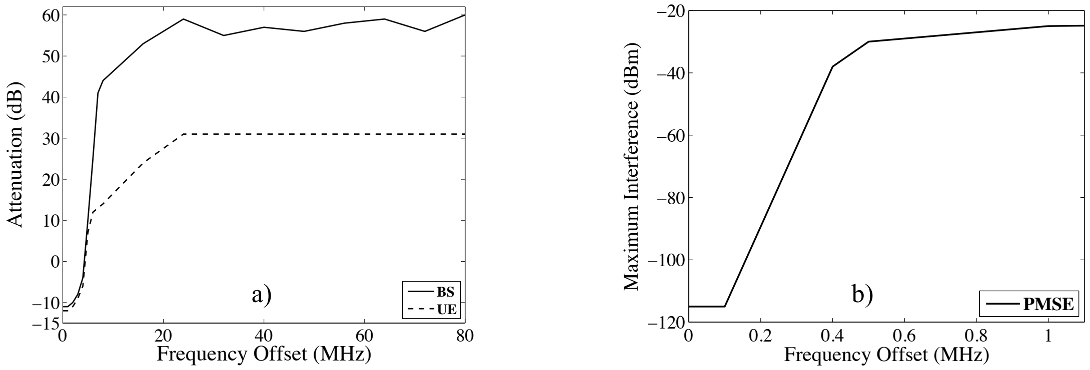

Figure 6 Protection Ratio function of a DVB-T receiver against a) SCN BS and SCN UE and b) maximum interference levels for a 200 kHz channel PWMS receiver.

At the PWMS receiver, maximum co-channel interference permitted should be below -115 dBm, taking as a basis analogue FM PWMS systems [5]. Figure 6 b) represents the absolute power level (in dBm) of maximum interfering signal, which might be tolerated by the receiver at a given frequency separation.

The DVB-T and PWMS link-budget calculations are described in Table 1 and Table 2.

For a worst-case scenario situation, the DVB-T receiver must be located at the edge of the cell coverage. For a minimum required SNR of 21 dB, target mean received signal power is -68.12 dBm (56.21 dBμV/m @ 10m). From the parameters defined in Table 1, this corresponds to a distance between DVB-T transmitter and receiver of 52.9 km.

Table 1 DVB-T link budget [6].

Parameter	Units	Downlink	Comment
Link bandwidth	MHz	7.60	Bandwidth occupied by link
Thermal noise density	dBm/Hz	-173.98	kTo
Receiver noise figure	dB	7	NF (Rec. ITU-R BT.1368)
Noise power over link BW	dBm	-98.17	Pn = kTB+NF plus any noise rise
Cell edge reliability	N/A	95%	SE42 modelling assumption
Gaussian confidence factor	N/A	1.645	N/A
Shadowing loss standard deviation	dB	5.5	P.1546
Wall loss standard deviation	dB	0	GE06
Total loss standard deviation	dB	5.5	Root of sum of STD squares
Loss margin	dB	9.05	Lmargin
Minimum SNR at cell-edge	dB	21	SNRmin for DVB-T
Target "mean" received signal level	dBm	-68.12	Ptarget = (Pn + SNR) + Lmargin
EIRP	dBm	79.15	P
Mean wall loss	dB	0	Lw
Receiver Antenna Gain	dBi	9.15	Ga (Rec. ITU-R BT.1368)
Max allowed path loss	dB	156.42	Lp = (P - Lw + Ga) – Ptarget
DTT transmitter height	m	200	Ht
DVB-T Rx height	m	10	Hr
Cell size	km	52.9	Rec. ITU-R P.1546

Table 2 PWMS link budget [6].

Parameter	Units	Downlink	Comment
Link bandwidth	kHz	200	Bandwidth occupied by link
Thermal noise density	dBm/Hz	-173.98	kT_0
Receiver noise figure	dB	6	NF
Noise power over link BW	dBm	-115	Pn = kTB+NF plus any noise rise
Minimum SNR at cell-edge	dB	21	SNRmin for PWMS
Target "mean" received signal level	dBm	-94	Ptarget = Pn + SNR
EIRP	dBm	10	P
Mean wall loss	dB	5	Lw
Receiver Antenna Gain	dBi	2.15	Ga
Max allowed path loss	dB	101.15	Lp = (P - Lw + Ga) - Ptarget
Wireless microphone height	m	1.5	Ht
PWMS Rx height	m	1.5	Hr
Cell size	m	100	Extended Hata SRD

The PWMS link is defined in such a way that a PSME Rx is at the edge of the coverage area with received signal equal to -95 dBm. With 10 dBm power emitted from the wireless microphone and using Extended Hata SRD propagation model, this corresponds to 100 m separation distance from the PWMS receiver.

Table 3 shows additional technical parameters [6] used to simulate a BS and UE. Sensing parameters such as detection threshold, Hidden Node Margin (HNM) and sensing bandwidth are only used when simulations are conducted using an autonomous sensing approach.

A key parameter for spectrum sensing is the detection threshold that is used by a cognitive device to detect the presence or the absence of a protected service’s transmission. The value is set to -120 dBm, as proposed by Ofcom [7]. HNM is zero when the interferer is a BS (downlink), since both DVB-T receiver and interferer antennas are above roof top level, and it is assumed that there is no obstruction between them. HNM is increased to 35 dB when the cognitive UE is the interferer (uplink), since DVB-T receiver antenna is usually not visible from the level where the device is located, typically 1.5 m above ground. This HNM value includes 99% of locations in any environment [7].

Table 3 SCN BS and UE transmitter technical parameters

Parameter	Units	Uplink	Downlink	Comment
Link bandwidth	MHz	5	5	LTE 5 MHz
In-block EIRP	dBm	23	56	P
Tx antenna height	m	1.5	10	Ht
Detection threshold	dBm	-120	-120	Ofcom proposal
Hidden node margin	dB	35	0	SE43 proposal
Sensing bandwidth	MHz	8	8	

4. Simulation Results and Analysis

A methodology for the derivation of the probability of interference between incumbent and TVWS secondary users was described in the previous section. We present in this section the results of simulations from two approaches and the resulting TVWS maps.

4.1 – Geolocation database approach

The impact of co-channel interference caused by LTE uplink or downlink transmissions is evaluated for the case of a DVB-T receiver. Plots of maximum allowable BS transmit power (EIRP in dBm) levels computed using the above-described techniques are shown in Figure 7 a). Probability of interference was set at 1%. The plot assumes that a 56 dBm maximum EIRP level is allowed and covers roughly an area with 250 km x 400 km.

The dark gray color indicates the protected contour areas of DVB-T receivers, where secondary users operation on that frequency would not be possible. The shapes of the contours are directly related to the receiver antenna pattern data. The white color indicates areas where BS operation is possible at full power (56 dBm) levels. Other shades of gray colors indicate areas where BS operation is possible, but power levels must be reduced to avoid interference. The same procedure was used considering that the interferer is now the UE, with maximum allowed EIRP level of 23 dBm. Figure 7 b) shows the plot produced.

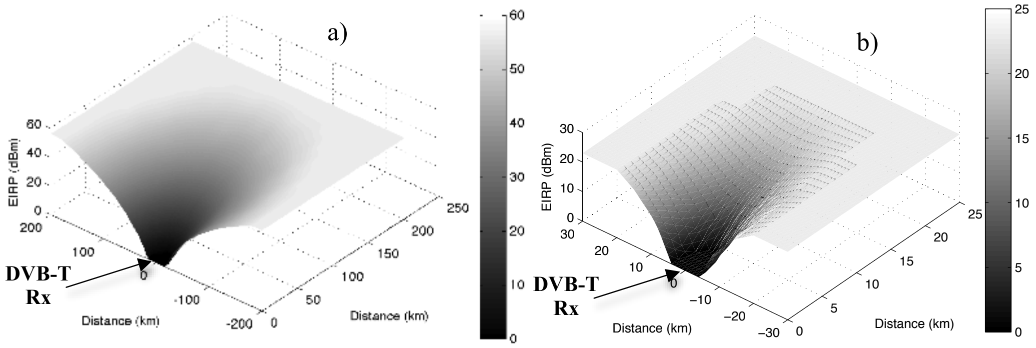

Figure 7 Allowed EIRP$_{max}$ with 1% probability of interference with DVB-T receiver for: a) BS and b) UE.

The results show that, due to the fact that the BS is in line of sight with the DVB-T antenna receiver, they should be placed at farther distance. Table 4 presents the calculated radius of the area around the DVB-T receiver for all cases studied, where BS or UE power levels should be less than or equal to 0 dBm. This area could be considered as a protected area by the geolocation database.

Table 4 Protected contour radius around DVB-T receiver against SCN transmitter emissions.

Parameter	Units	Uplink (UE)	Downlink (BS)	Comment
Protected contour	km	4.5	16	1 % interference

4.2 –Autonomous sensing approach

Plots were made to show the resulting EIRP_{max} that the WSD is allowed to transmit when spectrum sensing is used. For sake of simplicity, simulations are made only in one dimension, moving the interferer from the DVB-T receiver along a line, starting at point (1 km , 0) and ending at point (200 km , 0). As a reference for comparison, the same plot is made using the geolocation database approach, with EIRP_{max} set for 1% probability of interference.

Figure 8 a) shows the results when the interference comes from a UE. The two approaches present dissimilar curves, although the power increases with separation distances in both cases. Autonomous sensing is generally more conservative due to the high HNM used in the simulations. This value significantly limits the EIRP_{max} of the interfering device. For lower separation distances, the allowed emission power is too low to be considered useful for a communication system. The discontinuity in the autonomous sensing plot is due to the EIRP_{max} in-block limit function used in the simulation to control the emitted power from the UE.

The same method is conducted with a BS interferer and the results are presented in Figure 8 b). With HNM now set to 0 dB, the two graphs are showing similar trend for distance above 10 km. Once again, the influence of the EIRP_{max} in-block limit function is clearly visible in the autonomous sensing approach, with an increase power step at approximately 50 km. However, geolocation database approach result again in higher values of EIRP that can be used by the interfering BS.

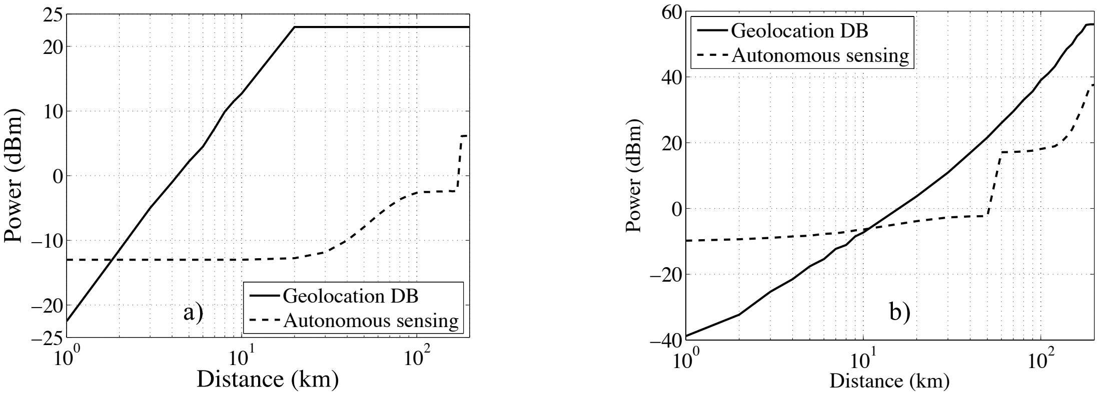

Figure 8 EIRP_{max} for a) UE and b) BS transmitters.

4.3 –Impact of wireless microphones activity in TVWS availability

For PWMS links, the criterion for interference to occur is to have a carrier to interference ratio (C/I) less than the minimum allowable value. Considering from Table 2 noise level at -115 dBm and the minimum required sensitivity level for high quality audio typically -100 dBm (6 dB below target mean received signal level),

$$C/(N+I)_{dB} = \text{Sensitivity} - \text{Noise Floor} = \text{-}100 - (\text{-}115) = 15\ \text{dB} \qquad (1)$$

Using a C/I requirement of 21 dB for current analogue FM equipment [6], further calculations shows that interference from SCN transmitters must stay below noise level by a factor equal to I/N = -5 dB, which results in I = -120 dBm. This parameter is used as a criterion to analyze interference simulation results for PWMS.

Co-channel interference is the first situation analyzed. For two distances between UE transmitter and PWMS receiver, the probability of interference is plotted in Figure 9 a) as a function of the interferer EIRP. Result shows that to maintain the interferer power below -120 dBm, UE 300 m away from a PWMS cannot emit above 2 dBm. If the distance is decreased to 100 m, emitted power from UE cannot surpass -16 dBm.

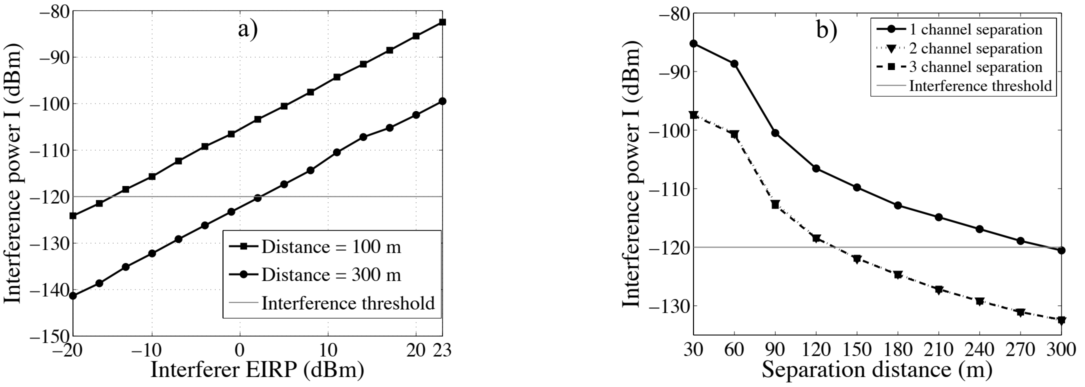

Figure 9 a) Co-channel power interference as a function of the interferer EIRP and b) Adjacent-channel interference as a function of the distance.

Other simulations were conducted to identify the necessary channel separation between incumbent PWMS and SCN UE, in order to maintain interference power below -120 dBm. From Figure 9 b), with one channel separation (8 MHz), UE can be used with full power at 300 m from the PWMS receiver. This distance can be further decreased to 145 m if a 16 MHz separation (2 channels) is used between primary and secondary links. No Further improvements are visible by increasing the channel separation above 16 MHz.

5. Conclusions

The analysis of co-channel and adjacent-channel interference from SCN BS and UE to DVB-T reception and PWMS was evaluated in the UHF band. Simulations showed that, due to the fact that BS are in line-of-sight with the DVB-T aerial antenna, it is the downlink that usually limits the white space area (16 km for BS and 4.5 km for UE). Two acquisition approaches were simulated and compared: geo-location spectrum database vs. autonomous sensing. Autonomous sensing artificially limits the maximum transmit power allowed for SCN operation due to the high hidden node margin used to protect primary users. Therefore geo-location database allows a more efficient use of TVWS. Finally, simulations show that safety distances between PWMS and secondary users depend on the SCN maximum transmitted power. Increasing the channel separation lowers the protection distance and hence increases the white space area. No improvements are visible by further increasing channel separation above 16 MHz.

Acknowledgments

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References

[1] CEPT Report 24, June 2008. Available at: www.erodocdb.dk/Docs/doc98/official/pdf/CEPTREP024.PDF
[2] SEAMCAT. Available at: http://www.seamcat.org/
[3] 3GPP TS 36.101 V9.2.0 - E-UTRA; User Equipment (UE) radio transmission and reception.
[4] CEPT Document SE43(10)32, 2010.
[5] Draft ETSI TR 102 546 V1.1.1_2.0.2 (2007-01)
[6] CEPT SE43(10)103-Annex3R1: Draft Report, 2010.
[7] Ofcom: cognitive access, 2010. Available at: www.ofcom.org.uk/consult/condocs/cogaccess/