DVB-T channels power measurements in indoor/outdoor cases

Adrian Kliks, Paweł Kryszkiewicz, Krzysztof Cichoń
Poznan University of Technology
Polanka 3, 60-965 Poznań
Email: {akliks | pkrysz | kcichon} @et.put.poznan.pl

A. Umbert, J.Pérez-Romero, F. Casadevall
Signal Theory and Communications Dept.
Universitat Politècnica de Catalunya (UPC)
Barcelona, Spain
{annau | jorperez | ferranc}@tsc.upc.edu

***Abstract*—In this paper the analysis of the spectrum occupancy in the TV band is provided based on the indoor and outdoor measurements campaigns carried out in Poznan, Poland, and Barcelona, Spain, in 2013. The goal of this work is to discuss the stability and other important features of the observed spectrum occupancy in the context of indoor/outdoor Radio Environment Maps database deployment. Reliable deployment of these databases seems to be one of the critical points in practical utilization of the TV White Spaces for cognitive purposes inside buildings and in densely populated cities.**

Keywords—TVWS; Measurement campaigns; REM; Spectrum occupation

I. INTRODUCTION

The problem of high spectrum underutilization has attracted the researchers, network operators and various governmental bodies all over the world. Numerous measurement campaigns have been performed in many places on all continents proving that around 20-30 percent of spectrum in the frequency band up to 3GHz is actively used for data transmission [1]-[6]. Clearly, this average value will vary depending on the exact frequency subband, location, date and time of the day, yet even in the densely populated cities and during the rush hours the maximum occupancy of the frequencies below 3GHz did not exceed the tens percents. Such a situation has motivated researchers to put significant effort on finding the way for novel techniques targeting better spectrum utilization. In consequence, the concept of cognitive radio and dynamic spectrum access appeared to be an effective solution to the aforementioned problems. Indeed, sophisticated cognitive-radio-oriented algorithms developed for the mobile terminals and for the base stations (or the whole network) are widely treated as the technical enabler of better spectrum utilization. After around fifteen years of investigation in that area, there are still various aspects that block the practical application of cognitive radio techniques in real life. However, it is worth noticing that from these investigations have several lessons have been learnt [7]-[9]. One of them is the observation that the delivery of wideband wireless Internet on wide areas using dynamic spectrum access is usually very hard. Thus, it is also said that the cognitive technologies (or more specifically white space transmission) can be considered but rather locally and mainly with the use of small-cell devices. In such an approach, low-power and small-range transmitters (such as femto- or picocells) are deployed inside or outside buildings in order to improve data rate and leading for higher spectrum utilization (please see various white papers available at e.g. [10]). One can observe that the deployment of such small base stations or access points would require detailed and reliable assessment of the spectrum occupancy at the considered location.

Thus, in this work we concentrate on the analysis of the measurement results obtained during the campaigns performed in 2013 in two European cities, i.e. Poznan in Poland and Barcelona in Spain. Some of the results have been already presented in the prior work of the authors [11][12]. In this paper, however, we have extended the observation focusing mainly on the measurements obtained during the drive tests. However, selected new indoor measurement results will be also presented. The indoor and outdoor measurements have been done focusing mainly on the TV band, which has been selected for many reasons. First, it offers relatively low transmit power due to well wall penetration characteristics compared to other higher frequencies. Moreover, TV band occupancy seems to be rather stable in the sense that the positions and transmit power of the digital terrestrial television (DTT) towers are fixed and rather do not change in time, as well as the TV channel allocation maps for a given country. One has to also remember that this band can be also used by Program Making and Special Events systems, and that the signals generated by these devices are of relatively thin bandwidth (around 200kHz). In consequence it can be assumed that the occupancy of that spectrum fragment will be rather stable and not change rapidly in time, thus it is predictable and can be utilized by white space devices. The aspect that has to be considered is the decision on the way, how the information of the current spectrum occupancy can be obtained. Due to the unreliability of the currently existing spectrum sensing algorithms, the implementation of the local databases (in form of Radio Environmental Maps) appears to be an attractive solution [13]-[17]. The goal of this paper is to present the conclusions that can be drawn based on a detailed analysis of the performed measurements and their implications in the context of a REM-based system implementation.

The rest of the paper is organized as follows. First we present our measurement setups used in Poznan University of Technology (PUT), and in Universitat Politècnica de Catalunya (UPC). In Section III we first analyze the results obtained during the drive tests, and then compare the indoor and outdoor measurements collected at the campuses in Poznan and Barcelona. The whole work is concluded in Section IV.

II. SYSTEM SETUP

The measurement campaigns have been performed in two different locations, in Poznan, Poland, and in Barcelona, Spain. Both indoor and outdoor measurements have been carried out, and moreover in Poznan drive tests have been applied. The measurement devices have been setup as follows:

a. for the indoor/outdoor measurements

In the case of indoor/outdoor measurements in both cities the DTV signal was captured by an omnidirectional antenna, which transfers it to a spectrum analyzer for initial data processing. Then the measured samples have been stored on the portable computer with the use of appropriate Matlab toolbox. In case of Poznan measurements active quad antenna, covering 40-850MHz (1-69TV channel), was connected via coaxial cable Lexton 3C2V of length 3m to the R&S FLS6 spectrum analyzer. In Barcelona scenario a passive discone antenna of type AOR DN753 was used, covering the frequency range from 75 to 3000MHz, and connected to ANRITSU MS2721B device. In both setups the resolution and video bandwidth of the spectrum analyzers were the same and equal to RBW=30kHz and VBW=100kHz, respectively.

b. for the drive-tests

In the case of street measurements the omnidirectional discone antenna AOR DA753 has been attached to the rooftop of a car. The aerial was connected to Rhode&Schwarz FSL v6 spectrum analyzer via low loss H155 cable. The spectrum analyzer was previously equipped with a card allowing for powering it from direct current (DC) source, i.e. lighter socket. The spectrum analyzer was connected (as in previous, indoor setup) via Ethernet cable to a laptop that runs Matlab with Instrumental Control Toolbox installed. Additionally, GPS receiver was placed on the top of the car and connected via USB cable to the laptop. It allowed us obtaining, for each measured frequency point, the exact geographical location of the measurement. As previously, RBW and VBW was set to 30kHz and 100kHz, respectively. The measurements path was made around Poznan city center in normal traffic conditions during daytime. The path recorded via GPS receiver is presented in Figure 1, where the distances are highlighted. It took about 1 hour to travel with the total length of more than 8km. The starting point (0,0) had GPS coordinates 52^{o}23’ 14.661’’ N 16^{o}55’24.795’’E. In order to illustrate the changes in the surrounding environmental conditions the route has been also projected on the Google Maps in Figure 1. One can observe changing scenarios – from loosely populated areas (marked on the map as *City center – Residential area*), through the city center with high tenement houses (*Old market square*), finishing on the ducts over the big river (*Warta river*) and sport areas (*Malta lake*). In this figure also the preview positions of the closest DVB-T towers are shown, highlighting also the distance from the PUT campus. Finally, let us stress the measurements have been done in the typical daily traffic conditions, i.e. depending on that traffic and on the switch-on- turn-on phases of the lamps at the crossroads, in some places the number of collected samples will be e.g. higher than in other places due to the travel speed.

III. MEASUREMENT RESULTS

A. Drive Tests

First, let us analyze the achieved results from the drive test, which are presented in form of the received power in the selected DVB-T channels (23, 27, 36, 39, see Table I) expressed in dBm per 8 MHz as the function of the distance from the start of the route (Figure 2) and as the function of time from the measurement beginning (Figure 3).

Table 1. List of scanned TV channels

TV channel	**Frequencies [MHz]**	**Carrier Frequency [MHz]**
23	486-494	490
27	518-526	522
36	590-598	594
39	614-622	618

Let us stress that these channels have been selected to be observed as they are the only channels occupied by the DVB-T signal at Poznan. One can observe quite high variations of the received signal power depending on the current position. For example, the black curve (the one at the top of Figure 2) represents the changes in the received signal power from the closest DVB-T tower. One can see the correlation between the types of scenario, in which the measurement have been performed (residential area or the surroundings of artificial Malta lake), and the value of the received power. The highest values of the received power have been observed near the river and Malta lake. Surprisingly, the variations of the received signal power in other TV channels were much smaller. In terms of numbers, the standard deviation of the received power in channel 36 was equal to around 7dB, while the variation of the received signal in the other channels was close to 3dB. Moreover, detailed analysis proved that the local, spatial variations of the signal power (observed in the TV channel show in Figure 2 and Figure 3, but also on the others 8MHz bands) are not so rapid, since no or very limited number of high spikes have been observed. If this is a case, there should exist a practical possibility for deployment of low power White Space Base Stations that will operate in the TV White Spaces with the support of the local Radio Environment Map.

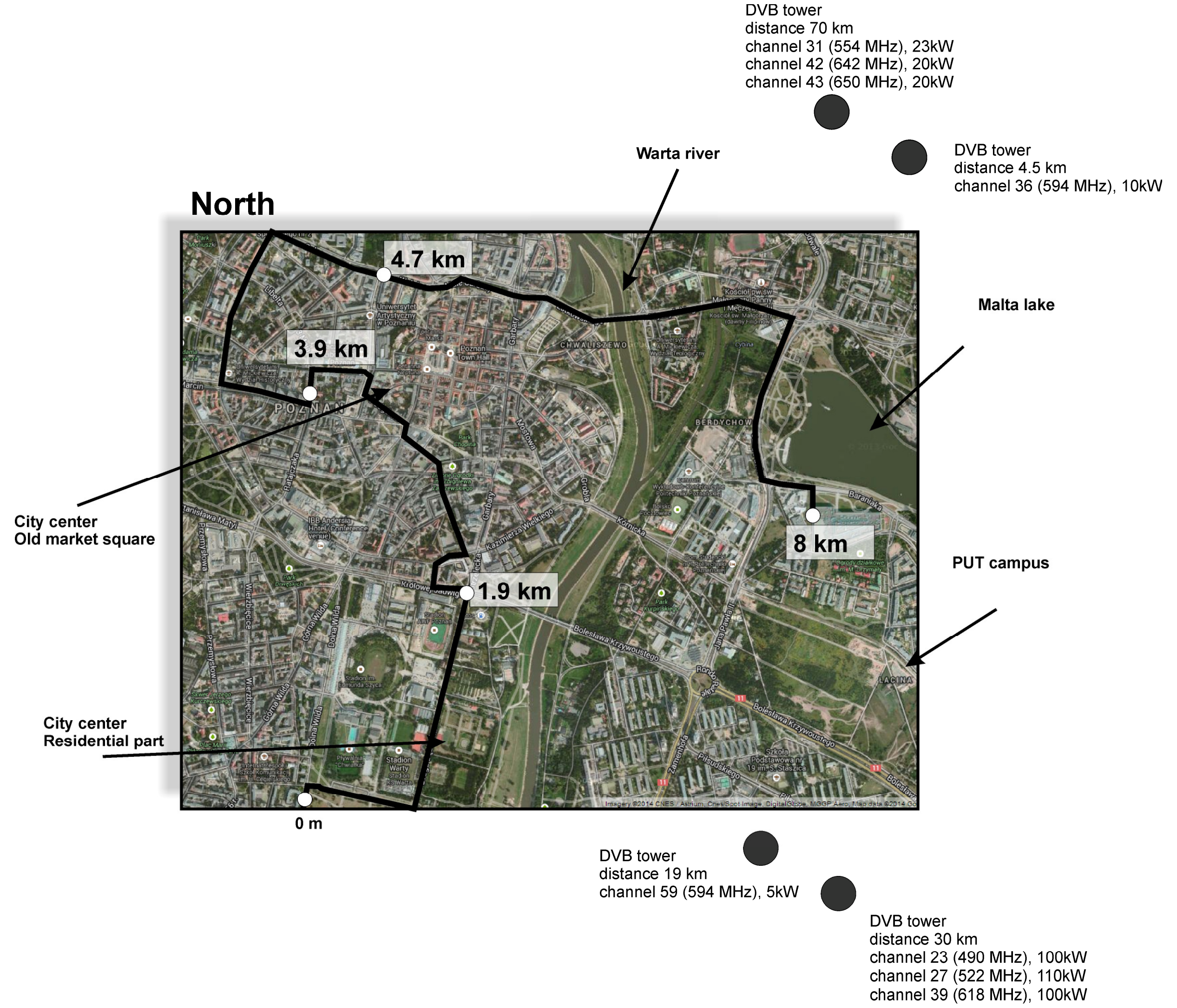

Figure 1. The route of car projected on the Google Map of Poznan

Analogously, similar conclusions can be drawn from the next figure (Figure 3), where the signal power is presented as a function of time. This figure coincides with Figure 2, however there is one significant difference – for around 400 seconds (around 6 minutes) the measurements have been performed in one place (the parking place near the castle located in the middle of Poznan). This period can be observed in Figure 2 in the range from the 1100 to 1500 seconds. The number of moving "objects" (including cars, humans and animals) in this area is rather big. Nevertheless, the received signal power in all TV channels seems to be stable. It suggests that the time variations of the signal are small and the influence of the moving elements in surrounding environment on the received power is also limited. Such a conclusion is very important since it builds the fundaments for the deployment of low power base stations that will operate in free TV channels.

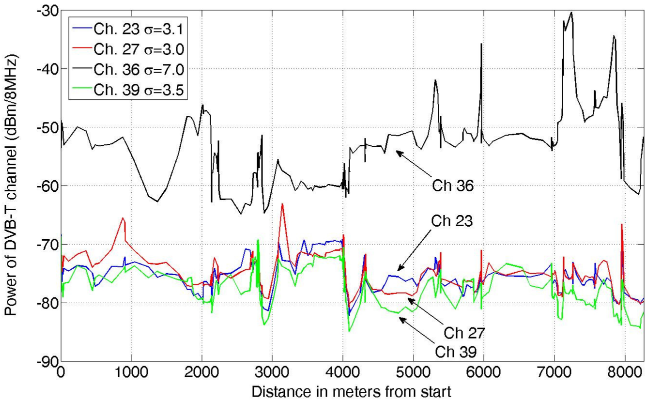

Figure 2. Received signal power as the function of the distance from the route start

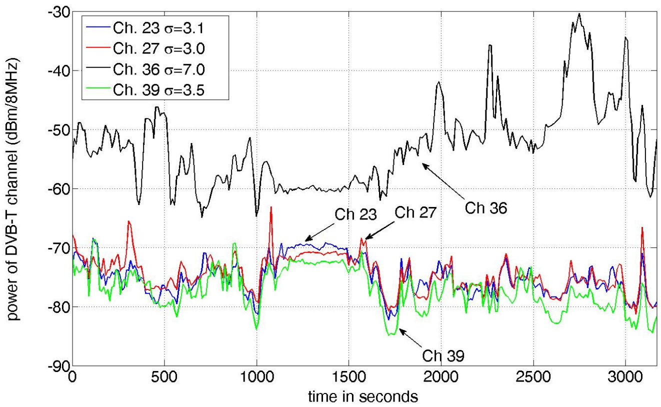

Figure 3 Received signal power as the function of the time passed from the route start

It is also worth noticing that very similar behavior of the received signal power is observed in all three TV channels (23, 27 and 39) transmitted from the same TV tower. Although the distance between the TV channels in frequency domain is even up to 120 MHz, the received signal powers as the function of time and distance are highly correlated.

All of the abovementioned observations and conclusions are of high importance since the measurements have been done in very typical day-time traffic conditions.

Finally, let us analyze the averaged Power Spectral Density of the received signal (Figure 4) and the box plot corresponding to the signal power calculated within the considered TV channels (Figure 5). In both figures the presence of four high-power DVB-T signals are observable at channels 23, 27, 36 and 39. The former figure illustrates three curves: the received power averaged during the whole route (middle plot, blue one), minimum observable power during the whole route (bottom plot, black one), and maximum observed power during the whole measurement time (upper plot, red one). Since the raster on the horizontal axes is 30kHz, one can observe that relatively high number of narrowband peaks are observable in various locations. It is also worth noticing that the two lower channels 23 and 27 in some locations are not detectable or at least severely degraded, since the received power in that band is close to the ambient noise power.

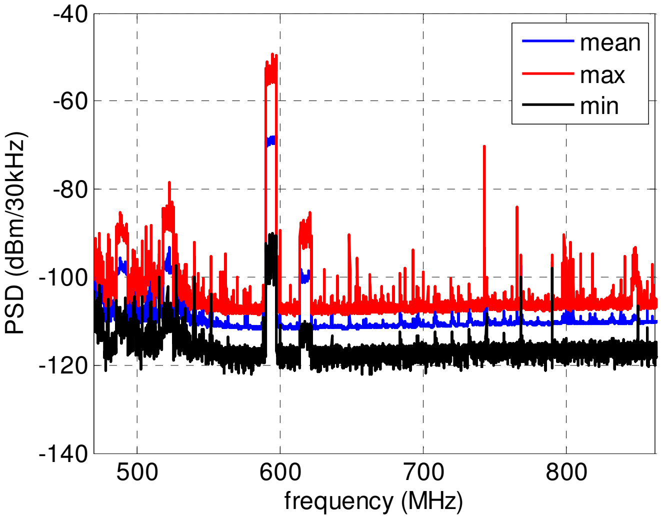

Figure 4. Power Spectral Density Function of the received signal samples during the whole drive test

Valuable observations can be drawn from the analysis of the Figure 5, where the box plot is shown for the frequency raster set to 8 MHz. The signal power received in channel 36 is rather very high regardless of the high values of variance. However, one can see that for the other channels the decision about the presence or absence of DVB-T signal is not so straight-forward. For example the mean measured power in channel 21 are very similar to those from channel 23, while in the former one the channel should be stated as vacant. Furthermore, although the mean value of the received power in channel 39 is less than in other occupied channels, the decision of the presence of the signal is rather easy due to the low ambient noise power observed in the adjacent frequency bands. Hopefully, local information about the received signal strength in the TV channels seems to be stable and weakly dependent on the surrounding environmental conditions.

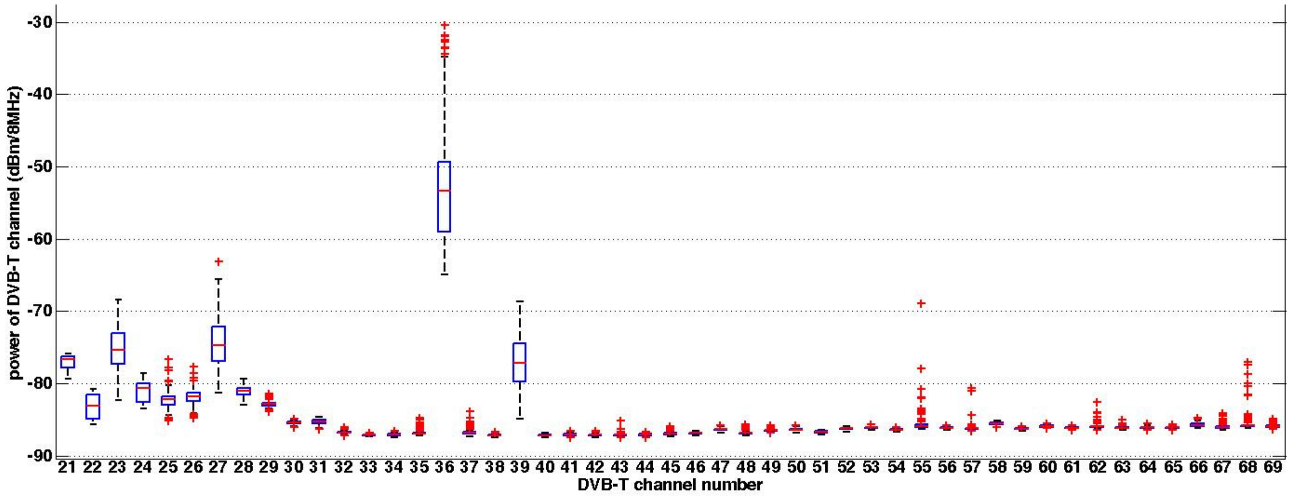

Figure 5. Box-plot for all available channels.

B. Indoor-Outdoor measurements

Detailed analysis of the performed measurements inside buildings of Poznan and Barcelona has been done in [11]-[12], and in further discussion we will base on the conclusions presented therein. In the nutshell, the main clue that originated from the measurements discussed in the referred paper is the following:

- The received signal power inside the building is rather stable in time, although it varies depending on the location
- The influence of the people walking inside the room on the observed signal power is strongly limited
- The attenuation of the walls is very strong, such that in many cases the reception of the DVB-T signal was not possible and the usage of external (e.g. roof-top) aerial was required
- A local REM data base seems a feasible option to characterize the spectrum occupation in different positions inside the building.

However, in this paper we would like to focus rather on the comparison between the street measurements (drive-tests) and the selected results observed by both stable (non-moving) roof-antennas and the antennas located inside buildings in the UPC campus. Analyzing the conclusions presented above in this subsection with the discussion done in the previous sections one can observe high similarity. It can be stated that both indoor and outdoor measurements prove the high local stability of the received signal power and weak influence of the moving objects on the received signal power. It further means that the deployment of the local white space REMs should be tractable.

Now, let us compare the values of the received power in Poznan and in Barcelona and try to generalize the results. Focusing on the results presented in Figures 3 to 5 it can be stated that the received power in the city center varies from -50 dBm/8MHz down to -80 dBm/8Hz. Let us now compare these values with the results obtained in Barcelona using stable (non-moving) measurement equipment. In Table II the referenced signal power in two TV channels – 26 and 61 – measured outside the building (at the rooftop) is shown. Then, in Table III and IV, received signal power in the same TV channels is presented but for four other indoor measurements locations. One can see that the received power outside the building is around -51 dBm, what is also around 20 dB higher better when comparing with the indoor measurements of the same TV channels signals. Analogous results have been obtained for other buildings and other locations, as presented in [11] and [12]. Clearly, the direct comparison of these two measurement scenarios is not fair, however, one can easily conclude that based on these results it can be stated that in most cases the outdoor signals are high enough to be easily detected, however, inside the buildings or in e.g. “street valleys” the received signal power can be so low that it would be impossible to detect the TV transmission. In other words, the measurements have proved that although the REM can cover wide areas, the granularity of its entries (records) shall be rather high. Moreover, when buildings are considered, the granularity of the REM should include the 3D dimensions since the floor inside the building plays a key role on the received power.

Table 2. Received signal power observed at Channels 26 and 61

	CH 26 [dBm/8MHz]	CH 61 [dBm/8MHz]
OUTDOOR REFERENCE	-51,27	-52,18

Table 3. Received signal power at channel 26

Channel 26	A	B	C	Avg	Attenuation (dB)
Underground	-68,19	-70,41	-74,39	-69,25	17,98
Ground floor	-69,75	-60,39	-70,77	-63,49	12,22
1st floor	-56,53	-54,34	-65,85	-57,85	6,58
2nd floor	-55,72	-56,02	-61,60	-57,60	6,33

Table 4. Received signal power at channel 61

Channel 61	A	B	C	Avg	Attenuation (dB)
Underground	-79,28	-82,47	-82,35	-80,69	28,51
Ground floor	-68,43	-66,01	-73,91	-68,47	16,29
1st floor	-62,26	-60,60	-72,96	-64,08	11,90
2nd floor	-67,79	-57,89	-73,56	-63,18	11,00

IV. CONCLUSIONS

In this paper the comparison of the measurement results done in two European cities (Poznan, Poland and Barcelona, Spain) has been done, focusing on the similarities and differences that occur between indoor measurements and drive tests. It has been stated that hopefully in both scenarios the stability of the TV channels is very high, and the influence of the surrounding moving objects is rather limited. Such an observation is crucial, since it is the basis for further work on the deployment of local outdoor and indoor radio environment maps for TV White Space Communications.

ACKNOWLEDGMENT

This work has been supported by the FP7 ICT NEWCOM# Network of Excellence in Wireless Communications (grant number 318306).

REFERENCES

[1] F.H. Sanders, „Broadband spectrum surveys in Denver, CO, San Diego, CA, and Los Angeles, CA: methodology, analysis and comparative

results", IEEE Int. Symposium on Electromagnetic Compatibility", tom. 2, str. 988-993, sierpień 1998

[2] S.W. Ellingson, „Spectral occupancy AT VHF: Implications for frequency-agile cognitive radios", VTC 2005 Fall, tom 2, str. 1379-1382, 2005

[3] Q. Zhao and B. M. Sadler, „A survey of dynamic spectrum Access", IEEE Sig. Proc. Magazine, tom 24, nr 3, str. 79 - 89, maj 2007.

[4] FCC, „Second/third report and order and memorandum opinion and order", United States, ET Docket No. 08-260 (2008), ET Docket No. 10-174 (2010), ET Docket No. 12-36, 2012.

[5] Ofcom, „Digital dividend: cognitive access - statement on licenceexempting cognitive devices using interleaved spectrum", UK, June 2009

[6] FCC, Second Memorandum Opinion and Order in the Matter of Unlicensed Operation in the TV Broadcast Bands (ET Docket No. 04-186), Additional Spectrum for Unlicensed Devices Below 900MHz and in 3GHz Band (EC Docket No 02-380), 23 September 2010.

[7] J. Zander, L.K. Rasmussen, K.W. Song, P. Mähönen, M. Petrova, R. Jäntti, J. Kronander, "On the scalability of Cognitive Radio: Assessing the Commercial Viability of Secondary Spectrum Access", , IEEE Wireless Communications, April, 2013, pp.28-35

[8] T. Dudda, T. Irnich, "Capacity of cellular networks deployed in TV White Space", IEEE International Symposium on Dynamic Spectrum Access Networks, 2012.

[9] A. Achtzehn, M. Petrova, P. Mähönen, "On the Performance of Cellular Network Deployments in TV Whitespaces", IEEE ICC 2012.

[10] www.smallcellforum.org/

[11] A. Kliks, P. Kryszkiewicz, J. Perez-Romero, A. Umbert, F. Casadevall, "Spectrum occupancy in big cities - comparative study. Measurement campaigns in Barcelona and Poznan", ISWCS 2013, pp.1,5, 27-30 Aug. 2013, Ilmenau, Germany

[12] A. Kliks, P. Kryszkiewicz, A. Umbert, J.Pérez-Romero, F. Casadevall, "TVWS Indoor measurements for HetNets", Workshop on Interference and Design Issues in Future Heterogeneous Networks at IEEE WCNC conference, Istambul, April, 2014

[13] Y. Zhao, L. Morales, J. Gaeddert, K. K. Bae, J.-S. Um, and J. H. Reed, "Applying radio environment maps to cognitive wireless regional area networks," IEEE DySPAN, pp. 115 – 118, April 2007

[14] J. van de Beek, T. Cai, S. Grimoud, B. Sayrac, P. Mähönen, J. Nasreddine, J. Riihijärvi, "How a Layered REM Architecture brings Cognition to Today's Mobile Networks", IEEE Wireless Communications, August, 2012, pp. 17-24.

[15] M.A. McHenry, P.A. Tenhula, D. McCloskey, D.A. Roberson and C.S. Hood, "Chicago Spectrum Occupancy Measurements & Analysis and a Long-term Studies Proposal", in Proc. of TAPAS'06 – 1st International Workshop on Technology and Policy for Accessing Spectrum, Boston, MA, USA, Aug. 2006.

[16] M. Wellens, J. Wu and P. Mähönen, "Evaluation of spectrum occupancy in indoor and outdoor scenario in the context of cognitive radio", in Proc. of CrowCom'07 – 2nd International Conference on Cognitive Radio Oriented Wireless Networks and Communications, Orlando, FL, USA, July 2007.

[17] E. Obregon, L. Shi, J. Ferrer, J. Zander, "Experimental Verification of Indoor TV White Space Opportunity Prediction Model", CROWNCOM, 2010.