

DVB-T Channels Measurements for the Deployment of Outdoor REM Databases

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Abstract—In this paper the analysis of the spectrum occupancy in the TV band is provided based on the outdoor measurements campaigns carried out in Poznań, Poland in 2013 and 2014. The goal of this work is to discuss the stability and other important features of the observed spectrum occupancy in the context of 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. The results obtained for outdoor scenario are briefly compared with the previous measurements conducted indoors in Barcelona, Spain, and in Poznań, Poland.

Keywords—channel measurements, DVB-T, spectrum occupancy, Radio Environment Maps.

1. 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% of spectrum in the frequency band up to 3 GHz 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 3 GHz 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 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 achieving 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 the authors concentrate on the analysis of the measurement results obtained during the campaigns performed in 2013 and 2014 in two European cities, i.e. Poznań in Poland and Barcelona in Spain, particularly focusing on the drive-tests conducted in Poland. Some of the results have been already presented in the prior work of the authors [11], [12], and particularly in [13], as this work is an extension of it. In this paper, previous observations have been extended, 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 better 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, as well as the TV channel allocation maps for a given country are fixed and do not change in time. 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 narrow bandwidth (around 200 kHz). 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 (REM), appears to be an attractive solution [14]–[18]. 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, the measurement setups used in Poznan University of Technology (PUT) and in Universitat Politècnica de Catalunya (UPC) are presented. In Section 3 first the results obtained during the drive tests are analyzed, and then the indoor and outdoor measurements collected at the campuses in Poznań and Barcelona are compared. The whole work is concluded in Section 4.

2. System Setup

The two street measurement campaigns, described in this paper, have been conducted in Poznań, Poland, whereas the indoor measurements (used in this work for comparison purposes) have been also carried out in Barcelona, Spain. The measurement devices have been setup in two configurations.

2.1. The Indoor/Outdoor Measurements

In the case of indoor/outdoor measurements in both cities the DVB-T signal was captured by an omnidirectional antenna and transferred to a spectrum analyzer, 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 Poznań measurements active quad antenna, covering 40–850 MHz (1–69 TV channel), was connected via coaxial cable Lexton 3C2V of length 3 m 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 3000 MHz, 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 = 30 kHz and VBW = 100 kHz, respectively.

2.2. 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 Rohde&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 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 in previous measurements, RBW and VBW were set to 30 kHz and 100 kHz, respectively. The photography of the car used for measurements is shown in Fig. 1.



Fig. 1. Car used for street measurements.

The measurements paths were made around Poznań city center in normal traffic conditions during daytime in October 2013. The first path recorded via GPS receiver is presented in Fig. 2, where the distances are highlighted. It took about 1 hour to travel with the total length of more than 8 km. The starting point (0,0) had GPS coordinates $52^{\circ} 23' 14.661''$ N $16^{\circ} 55' 24.795''$ E. In order to illustrate the changes in the surrounding environmental conditions the route has been also projected on the Google Maps in Fig. 2. 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 that 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, traffic lights, in some places the number of collected samples will be, e.g., higher than in other places due to the travel speed.

2.3. Test Campaign

As the first drive-test measurement campaign has been realized in autumn 2013, the second one was realized in analogous conditions (i.e., normal traffic conditions during daytime) but late winter, precisely in February 2014. The second road, illustrated in Fig. 3, was longer (around 25 km) and started just before the premises of the Faculty of Electronics and Telecommunications ($52^{\circ} 24' 0.66''$ N, $16^{\circ} 57' 20.51''$ E) and finished in the city center. One can observe that in that case the route led around the strict city center, providing different observations as compared to the

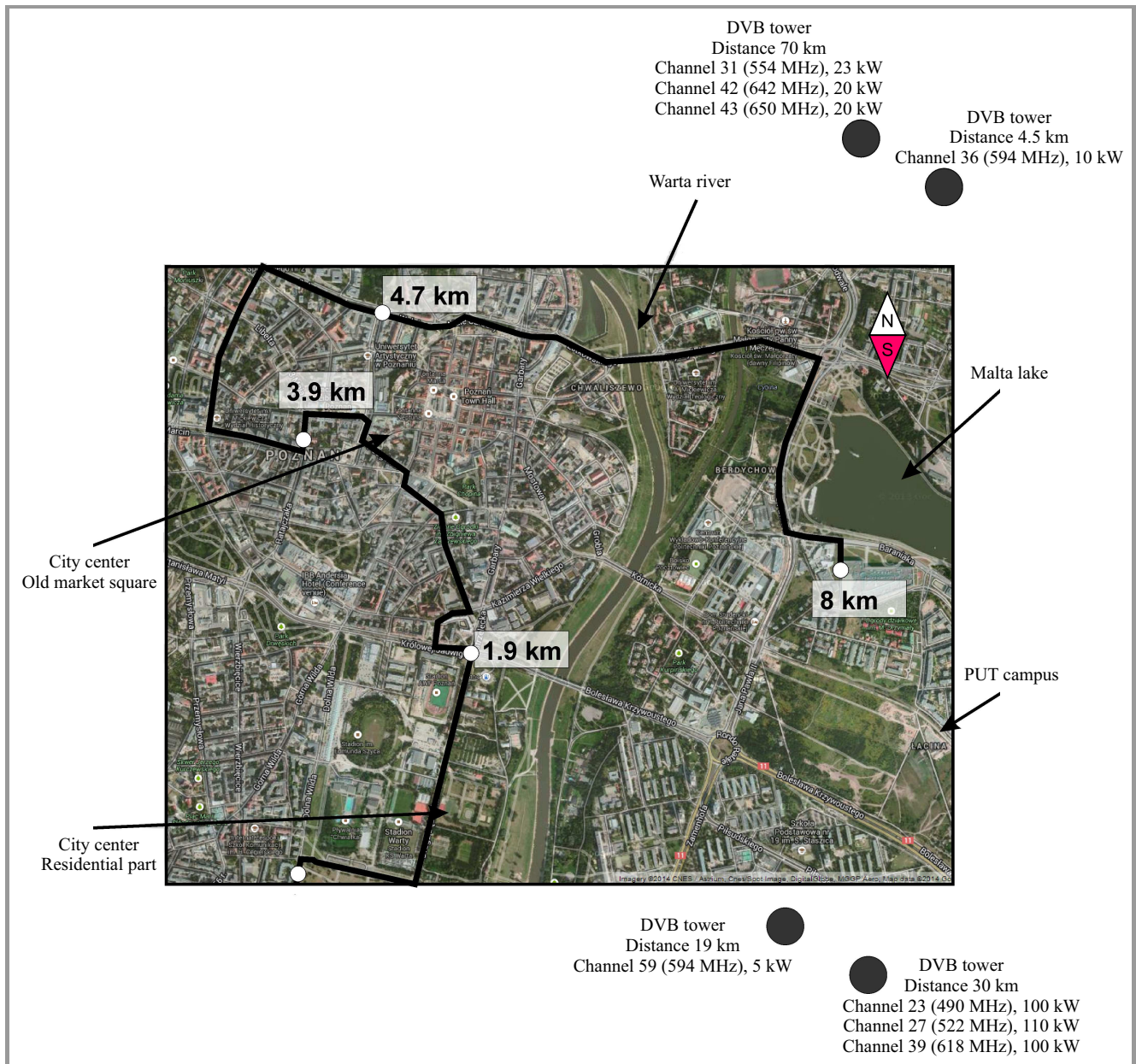


Fig. 2. The first route of car projected on the Google Map of Poznań.

results achieved in the first case. Moreover, one can notice the presence of the new DVB tower (called “Piatkowo”), which has been launched just between the two conducted measurement campaigns, probably in order to strengthen the received power at this channel. The perspective illustration of the location of the five DVB towers visible in the Poznań city center is presented in Fig. 4. It is also worth noticing that in Fig. 3 the position of two specific places has been marked (denoted as Place A and Place B), where the car used in the measurements stayed for longer time, i.e., it was intentionally stopped allowing for stable power measurements in one specific point as a function of time. Finally, for the sake of clarity the first route (Route 1) has been also highlighted in Fig. 3 in form of white dashed line.

3. Measurement Results

3.1. Drive Tests

First, let’s 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 1) expressed in dBm per 8 MHz as the function of the distance from the start of the route (Fig. 5 for first route and Fig. 6 for the second route) and as the function of time from the measurement beginning (Fig. 7 for first route and Fig. 8 for the second route).

Let’s stress that these channels have been selected to be observed as they are the only channels occupied by the DVB-T signal at Poznań. One can observe quite high variations

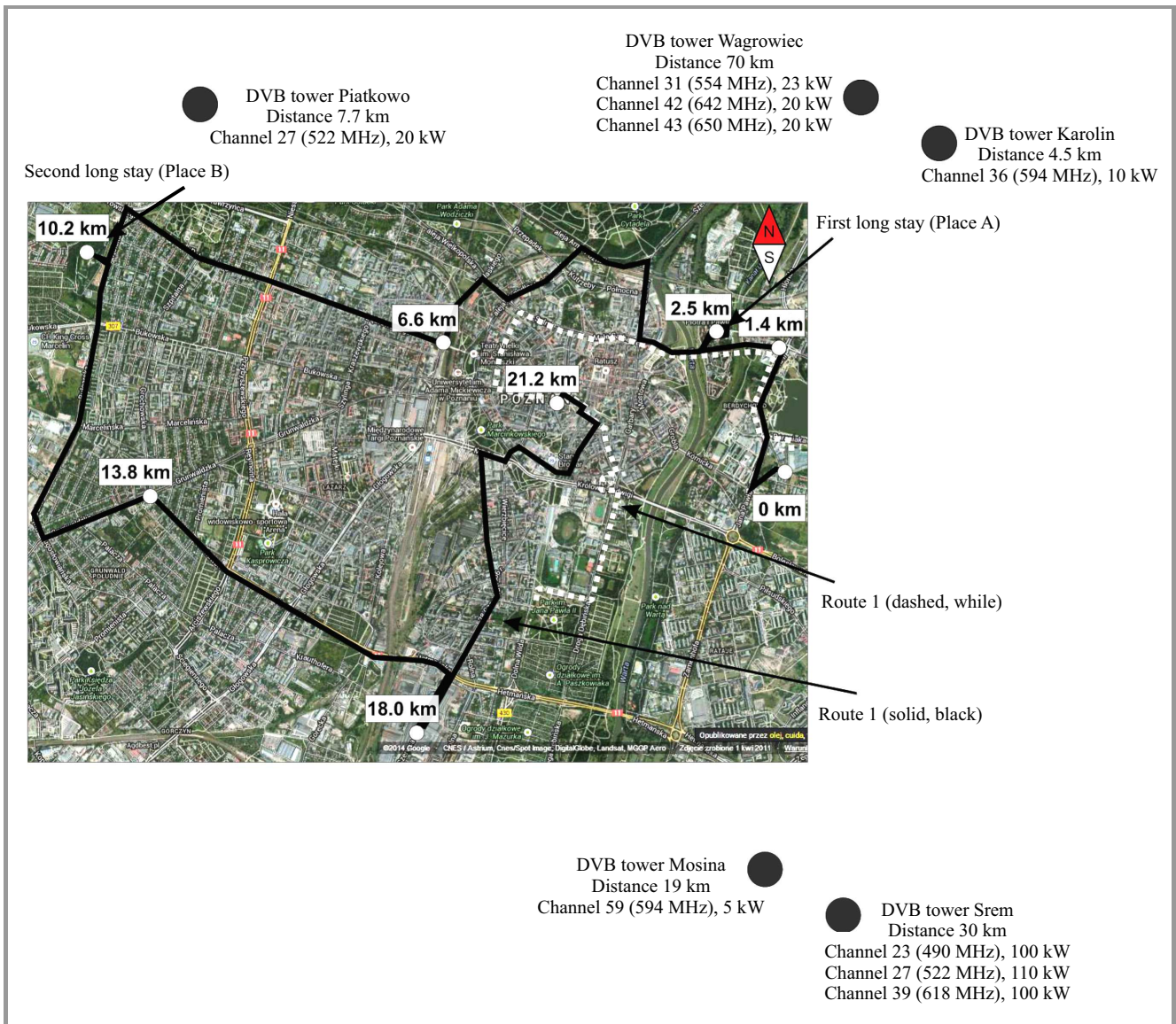


Fig. 3. The second route of car projected on the Google Map of Poznań.

of the received signal power depending on the current position. For example, the black curve (the one at the top of Figs. 5 and 6) 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 (see the Route 1). 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 7 dB (Route 1) or 6 dB (Route 2), while the variation of the received signal in the other channels was close to 3 dB (Route 1), and 4 dB (Route 2). Moreover, detailed analysis proved that the local, spatial variations of the signal power (observed in the TV channel shown in Fig. 5 to Fig. 6, but also on the other 8 MHz 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.

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

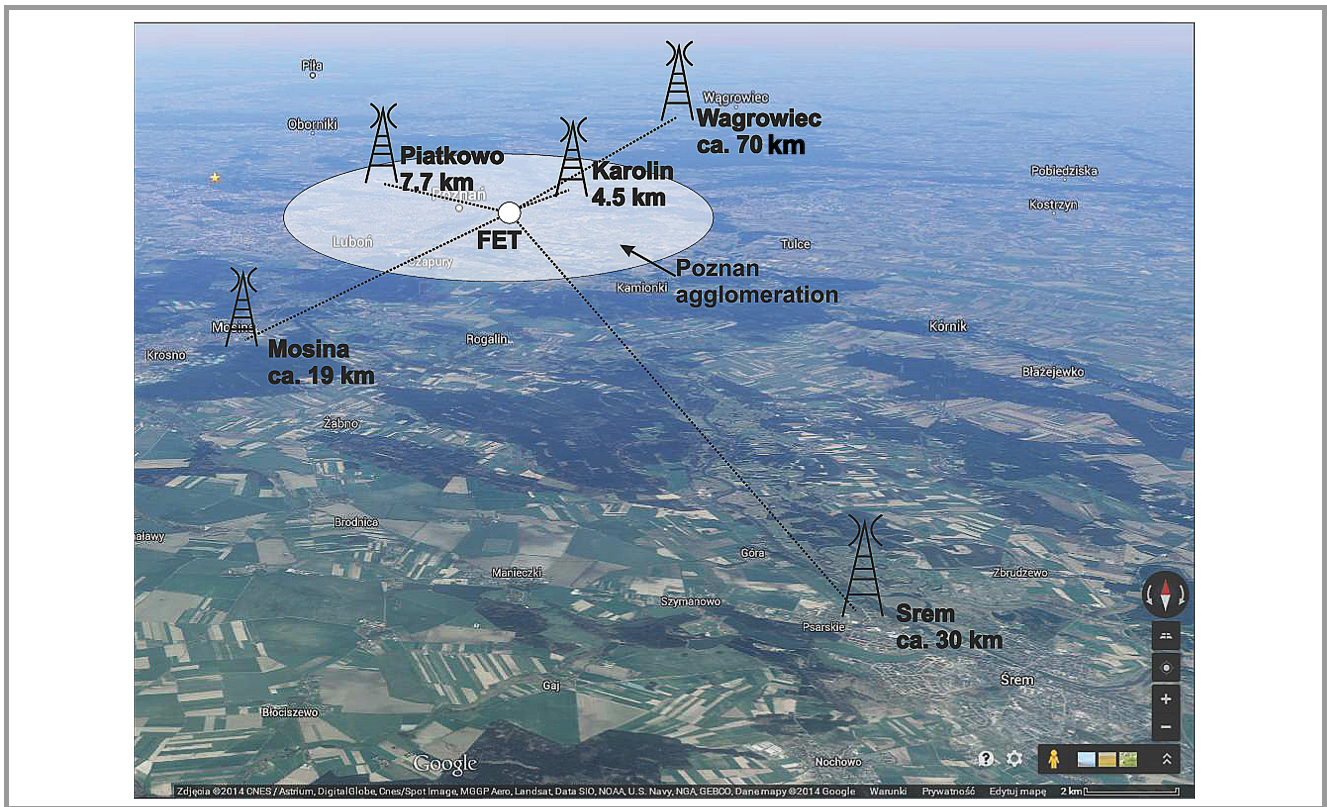


Fig. 4. Location of the DVB towers – perspective (FET – stands for the Faculty of Telecommunications).

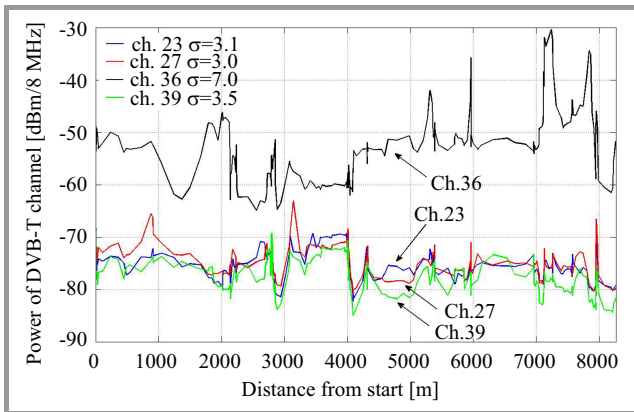


Fig. 5. Received signal power as the function of the distance from the route start – Route 1.

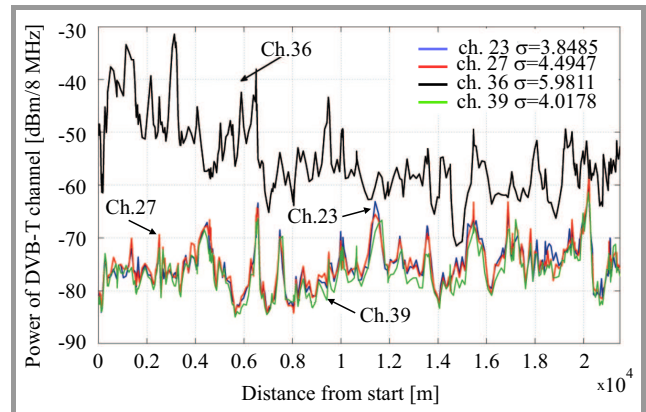


Fig. 6. Received signal power as the function of the distance from the route start – Route 2.

Analogously, similar conclusions can be drawn from the next figure (Figs. 7 and 8), where the signal power is presented as a function of time. The former figure coincides with Fig. 5, however there is one significant difference – for around 400 s (around 6 minutes) the measurements have been performed in one place (the parking place near the castle located in the centre of Poznań). This period can be observed in Fig. 7 in the range of the 1100 to 1500 s. The number of moving objects (including cars, people 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 fundamentals for the deployment of low power base stations that will operate in free TV channels. In order to prove this observation two additional places for long-time measurements during the drive tests have been selected, i.e., Place A (near the Poznań cathedral, close to the city center) and Place B (near military fort – Fort VII, a place where there are no high buildings in the closest vicinity). The measurements from that two specific places have been marked with the two ellipses in Fig. 8. One can observe

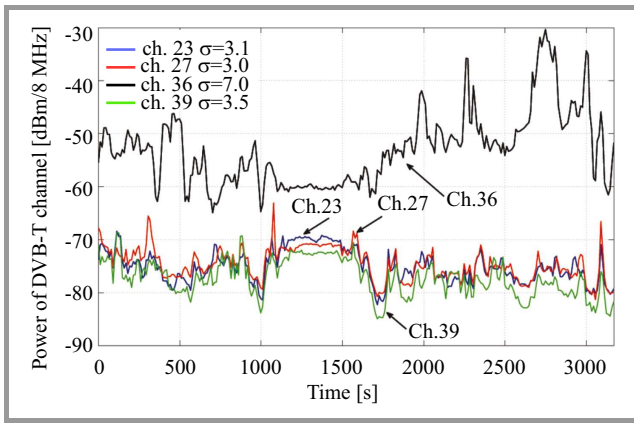


Fig. 7. Received signal power as the function of the time passed from the route start – Route 1.

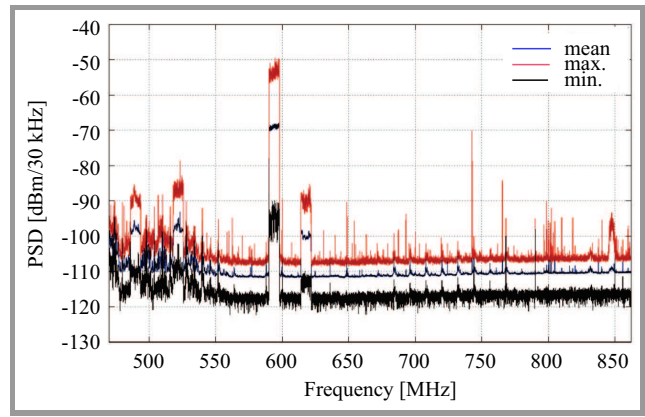


Fig. 9. Power Spectral Density Function of the received signal samples during the whole drive test – Route 1.

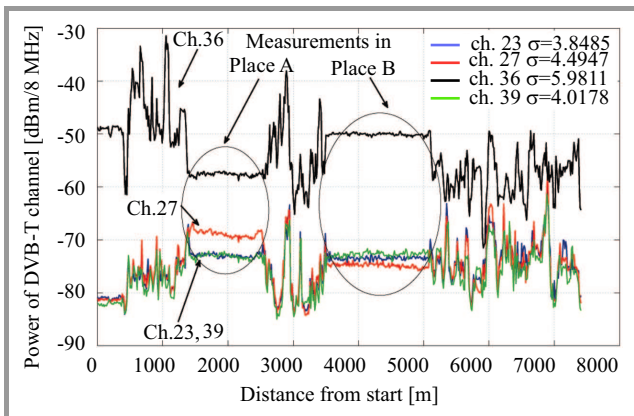


Fig. 8. Received signal power as the function of the time passed from the route start – Route 2.

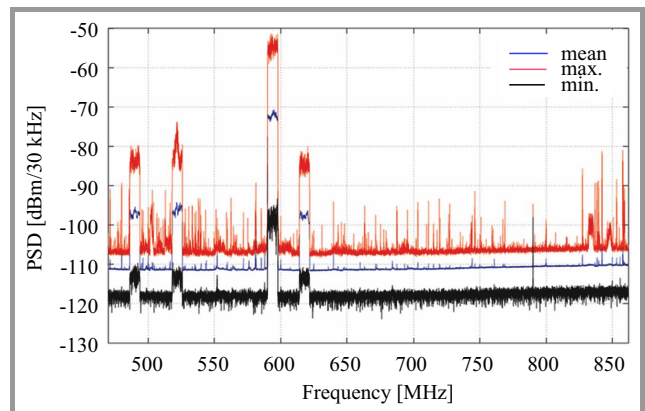


Fig. 10. Power Spectral Density Function of the received signal samples during the whole drive test – Route 2.

that the channel variations in these points can be stated as negligible.

It is also worth noticing that very similar behavior of the received signal power is observed in all other 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 above mentioned observations and conclusions are of high importance since the measurements have been done in very typical day-time traffic conditions.

Finally, let's analyze the averaged Power Spectral Density of the received signal (Fig. 9 for the Route 1 and Fig. 10 for the Route 2) and the box plot corresponding to the signal power calculated within the considered TV channels (Fig. 11 for Route 1 and Fig. 12 for Route 2). In these 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), minimum observable power during the whole route (bottom plot), and maximum observed power during the whole measurement time (upper plot). Since the raster on the horizontal axes is 30 kHz, 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.

Valuable observations can be drawn from the analysis of the Fig. 11, 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 straightforward. For example the mean measured power in channel 21 is very similar to that 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. Analogous conclusions can be drawn from the analysis of the box-plot related to the second route, i.e., Fig. 12. However, some differences can

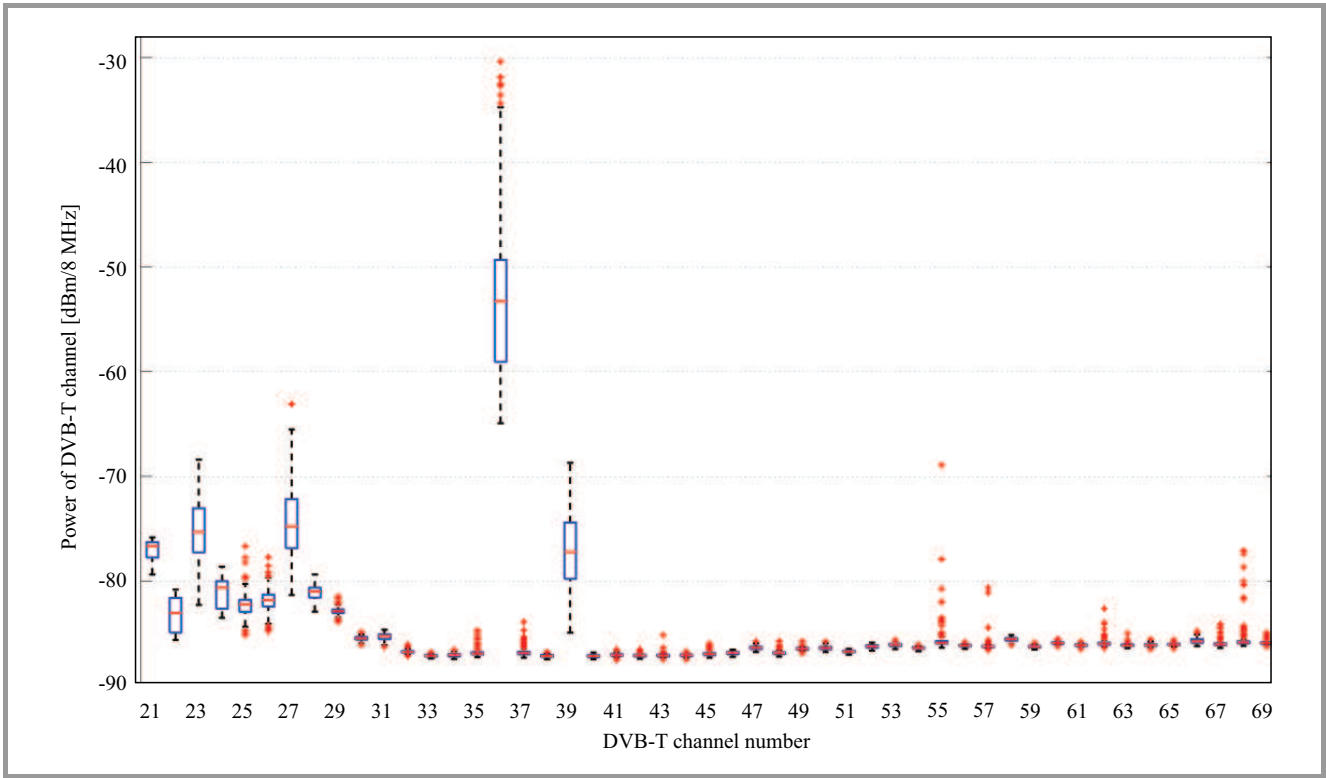


Fig. 11. Box-plot of the received signal power along the whole route – Route 1.

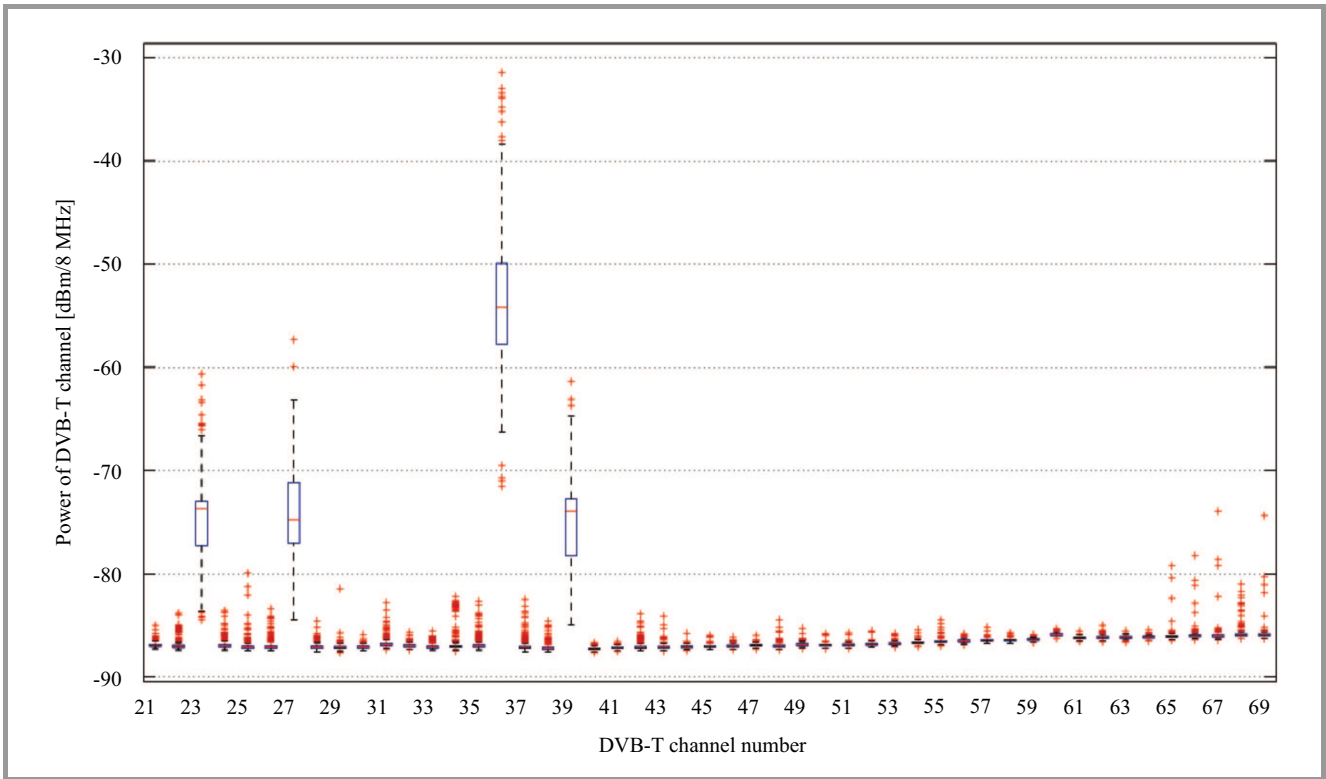


Fig. 12. Box-plot of the received signal power along the whole route – Route 2.

be noticed between these two plots. First, the variance of the received power within channel 27 is higher for the second route. This is due to the fact that the new DTT tower has been launched between the first and second measurement campaigns. On the other hand, the variance observed at channel 39 is also higher for the second route, but this time the reason could be just the fact that in the two measurement campaigns different routes have been used. Finally, there is relatively high power observed at the lower frequencies for the first route (channels up to 31), which is not observed in the second case. It is not straight-forward to decide on the reason for that phenomenon. For sure it is not caused by different system setup, since the same measurement hardware and car have been used in both campaigns. This power in lower TV channels can be some sort of interference coming from “unknown sources”. Similarly, some differences can be observed at higher TV channels.

3.2. Indoor-Outdoor Measurements

Detailed analysis of the performed measurements inside buildings of Poznań and Barcelona has been done in [11], [12], and in further discussion will be based on the conclusions presented therein. In a 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 the authors 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's compare the values of the received power in Poznań and in Barcelona and try to generalize the results. Focusing on the results presented in Figs. 3 to 5 it can be stated that the received power in the city center varies from

Table 2

Received signal power observed at channels 26 and 61 expressed in [dBm/8 MHz] – in Barcelona

	Ch. 26	Ch. 61
Outdoor reference	-51,27	-52,18

Table 3

Received signal power at channel 26

Ch. 26	A	B	C	Avg.	Att.
Basement	-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

Ch. 61	A	B	C	Avg.	Att.
Basement	-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

-50 dBm/8 MHz down to -80 dBm/8 MHz. Let's now compare these values with the results obtained in Barcelona using stable (non-moving) measurement equipment. In Table 2 the referenced signal power in two TV channels – 26 and 61 – measured outside the building (at the rooftop) is shown. Then, in Tables 3 and 4, 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 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 valley” 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, as seen in Tables 3 and 4.

4. Conclusions

In this paper the comparison of the measurement results of the two street drive-tests has been presented and compared with the indoor measurements done in two European cities, 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.

Acknowledgements

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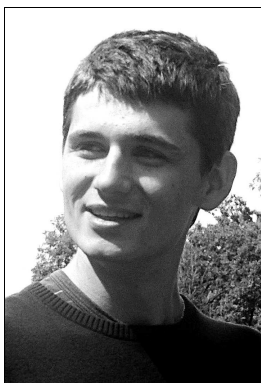
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