TVWS Indoor measurements for HetNets

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Abstract— **In this paper the results of intensive measurement campaigns performed inside the buildings in two locations (Poznań, Poland and Barcelona, Spain) are presented and analyzed to investigate their potential in the generation of digital indoor radio environment maps. The existence of such detailed and stable maps will allow for further definition of the allowed transmit power of small cell transceivers operating within indoor heterogeneous networks and making use of TeleVision White Spaces (TVWS). The analysis concentrates on the stability and repeatability of the measured values both over time and location, as key elements enabling the creation of aforementioned digital maps.**

Keywords— TVWS, heterogeneous networks, indoor measurements

I. INTRODUCTION

Recent years have witnessed an exponential growth of the demand for mobile broadband services associated with the massive penetration of the new generation of wireless user equipment (smartphones, tablets, etc.) in the population and the proliferation of bandwidth-intensive applications. This trend is expected to even increase in the future with the introduction of novel applications involving High Definition Video, 3D, virtual reality, etc. Most of this new data traffic is being generated indoors, which requires increased link budget to provide higher data rates and achieve satisfactory user experience. Then, for a better provision of such high capacity demanding service types the classical cellular network concept is being shifted towards the so-called Heterogeneous Networks (HetNets) composed of both traditional large macrocells and small cells of different sizes such as picocells, femtocells, etc. Such small cells are expected to cover small areas (in the order of 10-100m), including also indoor, thus being efficient in providing high capacity to their served users and to offload traffic from the macrocells in densely populated areas where traffic is usually non-homogeneously distributed.

The deployment of HetNets and the massive introduction of small cells in dense urban scenarios will necessarily involve the introduction of efficient interference mitigation techniques and coordination mechanisms to reduce inter-cell interference in case that the same frequency is shared between macro and small cells. Alternatively, the use of different frequencies is also a possibility, at the expense of increasing the requirements in terms of spectrum demand. In this respect, the shared use of licensed frequency bands such as TeleVision White Spaces (TVWS) is seen as a relevant solution thanks to the more reduced coverage area and power levels of small cells, which makes easier the task of finding a sufficiently large TVWS to ensure the desired coverage. In fact, different works in the literature have recognized recently the potentials of using TVWS in small cell scenarios [1]-[4], particularly for expanding LTE spectrum.

Under the above framework, this paper focuses on analysing the potentials of TVWS for deploying small cells in indoor scenarios. This scenario is considered as particularly relevant for two main reasons. Firstly, most of broadband data traffic is generated indoors, so the deployment of small cells inside buildings (e.g. 3G and LTE femto-cells, APs, etc.) becomes a better solution to achieve high capacities than providing coverage from external cells. Secondly, it is expected that the availability of TVWS spectrum can be increased indoors thanks to the building penetration losses between indoor small cells and TV receiving antennas usually located at the rooftop. Due to the intrinsic randomness associated to propagation in indoor environments, the assessment of the capability of using TVWS needs to be done by means of exhaustive measurements. Then, in this paper we intend to analyse this capability through an indoor measurement campaign made in two different locations of Europe, namely Barcelona and Poznan, exhibiting different occupation of the TV channels. As a difference from prior works such as [5], where some initial experimental studies based on indoor measurements were already carried out, validating a previous simulation model and identifying availability of TVWS in an indoor scenario, in this paper we also intend to experimentally analyse the characteristics of the indoor propagation of TV signals in terms of effects such as the stability over time, the effects of multi-path at different distances, etc. which need to be carefully taken into account when considering the possibility of deploying indoor small cells using TVWS.

The paper is organized as follows. Sec. II provides considerations on the deployment of indoor small cells using TVWS and motivates the need of performing measurements. Sec. III describes the measurement locations and the set-up. Measurement results are analysed in Sec. IV and Sec. V discusses the applicability of these results to the deployment of small cells. Conclusions are summarized in Sec. VI.

II. CONSIDERATIONS FOR DEPLOYING INDOOR SMALL CELLS USING TVWS

This section elaborates on the considerations and requirements that need to be taken into account when addressing the deployment of indoor small cells using TVWS.

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The interference generated by the small cell transmitter to the DTV receivers should be below the acceptable limits not to degrade the reception capability. Different works [6][7] have characterized the required rejection threshold of Desired to Undesired received power (D/U) at the TV receiving antenna. In [7] the co-channel rejection ratio is 15.5 dB and the first adjacent channel rejection ratio is -33 dB for desired signals between of -53 dBm (moderate desired signal) and -68 dBm (weak desired signal) and it raises up to -20 dB for strong desired signals of -28 dBm. For the rest of adjacent channels the rejection ratio is between -40 dB and -57 dB for moderate and weak desired signals and -20 dB for strong desired signals.

The position of the TV receiving antenna should be considered. Usually, antenna will be outdoor and located on the rooftop, but indoor antennas may also exist. In the first case the indoor small cells will benefit from the larger isolation provided by walls and floors penetration losses, which may allow small cell operation in more channels than in the case of indoor antennas, where the small cell transmitter may be located very close to the TV receiving antenna thus requiring larger frequency separations. In general, the interference generated by the small cell can be received through the TV antenna, through the coaxial cable between the antenna and the TV receiver, or directly via receiver chassis. In the studies carried out in [5] it was concluded that the main contribution was the one received at the antenna, while the other two contributions could be neglected.

The propagation in an indoor environment can be influenced by multiple effects in addition to the penetration losses that are usually captured in classical indoor propagation models. First, the lack of line of sight leads to multi-path effects causing large variations of the received signals in relatively short distances (also due to numerous reflections from walls). Second, the influence of the people moving around the building can also affect the stability of the received signals during different periods of the day, particularly when considering office or university buildings where some rooms can be very crowded at some time, and then suddenly many people can be moving together towards other locations (e.g. to the cafeteria, to classroom, etc.). Such effects can highly influence on the interference that the small cell transmitter can generate over the TV receiving antenna. They will also influence on the coverage area of the small cell inside the building and on the interference that the TV signals may generate over small cell receivers.

The abovementioned propagation effects are tightly related with the quotidian life in the considered building so they can hardly be captured by means of propagation models. Therefore, measurement campaigns are needed to quantify up to which level these effects may influence on the small cell deployment. By a proper analysis of the measurements taken at the different locations it will be possible to better specify the areas where the different channels could be utilized. Eventually, this would lead to the generation of local Radio Environmental Maps (REM) at the building level. With this general target in mind, this paper intends to provide further insight into the propagation effects that are observed over DTV signals in an indoor environment by means of a measurement campaign.

III. Measurement Locations and Set-Up

The measurement campaign has been carried out at two big European cities, namely Barcelona and Poznań, both of them with different existing allocations of DTV channels.

The location for the measurements in Poznań was the building of the Faculty of Electronics and Telecommunications of the Poznań University of Technology (PUT) (52 º 24' 1.58" N, 16º 57' 21.06" E). A total of 7 DTV channels were detected at the rooftop. Among them, detailed indoor measurements have been performed at channels 23 (490 MHz), 27 (522 MHz), 36 (594 MHz) and 39 (618 MHz). Channels 23, 27 and 39 come from a transmitter distanced by 31.5 km and transmitting at 100 kW power. Channel 36 is a SFN (Single Frequency Network) and comes from two transmitters distanced by 4.6 km and 19.2 km with transmit powers 10 kW and 5 kW, respectively.

The location for the measurements in Barcelona was the building of the Department of Signal Theory and Communications in the UPC Campus Nord (latitude: 41º 23' 20" N; longitude: 2º 6' 43" E; altitude: 175 m). A total of 21 DTV channels were detected at the rooftop. Among them, detailed indoor measurements have been performed at channels 26 (514 MHz), 44 (658 MHz) and 61 (794 MHz), located in the lower, middle and upper parts of the DTV spectrum, respectively. The three channels are received from a transmitter located at 3.1 km with transmit power of 10 kW for channel 26 and 7.4 kW for channels 44 and 61.

In both locations two types of measurements have been carried out, i.e. we have checked how the measured parameters changes in time and how they behave as a function of the location inside the building. In the first case dedicated measurement points have been identified (seven points in Poznan and four points in Barcelona, indicated as black dots in Fig. 1), while for the second case the measurements were done along the buildings' corridors (around 100m long in case of Poznan campus, and 30m long for Barcelona case).

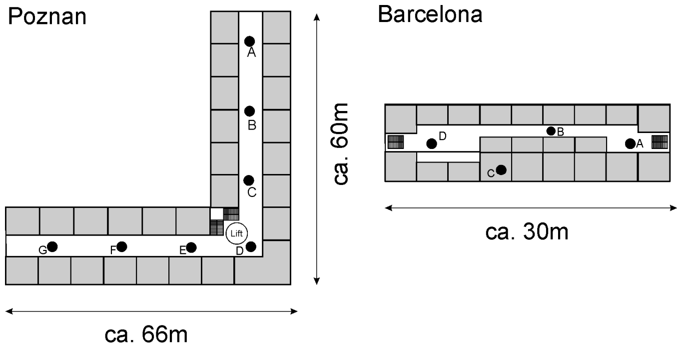

Fig. 1. Illustrative floor plans for both locations (Poznan and Barcelona) with indicated measurement points

In both cases the DTV signal was measured by the omnidirectional antenna, then sent to the spectrum analyzer and finally stored on the portable computer via Matlab. 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 the passive discone antenna of type AOR DN753 was used, covering the frequency range from 75 to 3000MHz, and connected to ANRITSU MS2721B device. The system setups are shown in Fig. 2 and Fig. 3. In both setups the resolution and video bandwidth of the spectrum analyzers were the same and equal to RBW=30kHz and VBW=100kHz, respectively.

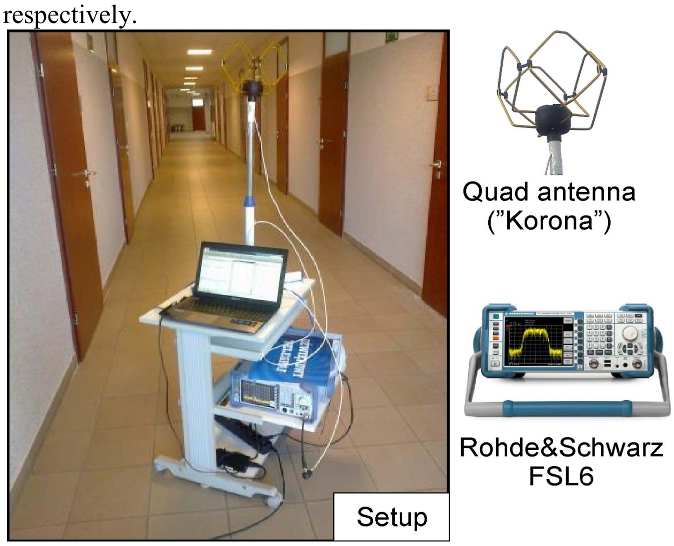

Fig. 2. Measurements system setup in Poznan

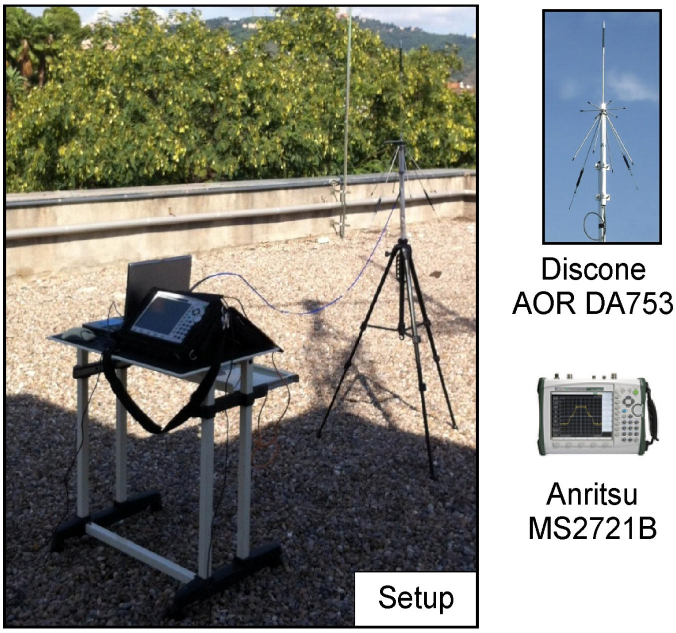

Fig. 3. Measurements system setup in Barcelona

IV. Measurement Analysis

The goal of the performed measurements was to analyze various parameters of the TV signals received inside the building for possible reuse of vacant TV channels for deployment of heterogeneous networks. In this section we present some of the measured features of the received signals that are important for future creation of digital REMs used for deployment of small-cells indoor transceivers. These are inter alia stability of the received signal over time, variations of the received power in terms of location, and influence of walls or people working/walking inside the building.

1) *Average received power*

As the first step the averaged power of the received TV signals in the selected points across the vertical profile of the building was measured (thus in each of the selected points the average received power within one 8-MHz width TV channel was measured on the roof, and on second, first and ground floor, and – only for Barcelona – in the underground). Some selected measured values for different channels for Poznan and Barcelona are presented in the tables below. Moreover, the plot of the observed power spectral density in point D at rooftop and in the second floor is shown in Fig. 4. From that figure one can observe quite big differences between the roof and indoor measurements, i.e. besides high roof/walls attenuation various spikes of relatively high power have been detected indoor that come from various internal (i.e. deployed inside building) devices e.g. video cameras, computers, lightning etc. mounted near point D. Moreover, the amplification of the noise floor (which can be treated as ambient noise) observed in the frequency range 500- 700MHz is probably caused by some internally deployed devices.

TABLE I. AVERAGE RECEIVED POWER IN BARCELONA, CH. 26

Channel 26	A	B	C	D
Rooftop	-44.41 dBm	-44.41 dBm	-44.41 dBm	-44.41 dBm
2nd floor	-62.06 dBm	-60.94 dBm	-63.13 dBm	-61.12 dBm
1st floor	-56.61 dBm	-57.06 dBm	-66.27 dBm	-55.96 dBm
Ground floor	-64.38 dBm	-57.67 dBm	-72.83 dBm	-63.00 dBm
Underground	-70.99 dBm	-68.71 dBm	-76.17 dBm	-74.40 dBm

TABLE II. AVERAGE RECEIVED POWER IN BARCELONA, CH. 44

Channel 44	A	B	C	D
Rooftop	-46.76 dBm	-46.76 dBm	-46.76 dBm	-46.76 dBm
2nd floor	-60.77 dBm	-55.21 dBm	-60.52 dBm	-59.46 dBm
1st floor	-56.66 dBm	-51.89 dBm	-56.90 dBm	-63.62 dBm
Ground floor	-58.97 dBm	-52.29 dBm	-63.34 dBm	-59.73 dBm
Underground	-69.71 dBm	-67.08 dBm	-70.49 dBm	-69.56 dBm

TABLE III. AVERAGE RECEIVED POWER IN BARCELONA, CH. 61

Channel 61	A	B	C	D
Rooftop	-58.12 dBm	-58.12 dBm	-58.12 dBm	-58.12 dBm
2nd floor	-68.88 dBm	-65.65 dBm	-70.98 dBm	-67.19 dBm
1st floor	-64.28 dBm	-60.45 dBm	-74.23 dBm	-68.24 dBm
Ground floor	-67.43 dBm	-64.04 dBm	-76.07 dBm	-63.61 dBm
Underground	-78.10 dBm	-76.85 dBm	-77.54 dBm	-77.77 dBm

TABLE IV. AVERAGE RECEIVED POWER IN POZNAN, CH. 23

Channel 23	A	B	C	D
Rooftop	-48.29 dBm	-49.78 dBm	-44.62 dBm	-46.68 dBm
2nd floor	-71.61 dBm	-68.68 dBm	-68.24 dBm	-64.09 dBm
1st floor	-73.25 dBm	-71.66 dBm	-79.14 dBm	-73.54 dBm
Ground floor	-80.31 dBm	-79.38 dBm	-81.37 dBm	-76.20 dBm
Channel 23	**E**	**F**	**G**	
Rooftop	-	-	-	
2nd floor	-63.75 dBm	-60.44 dBm	-63.94 dBm	
1st floor	-73.07 dBm	-71.17 dBm	-76.19 dBm	
Ground floor	-76.03 dBm	-77.2 dBm	-78.77 dBm	

TABLE V. AVERAGE RECEIVED POWER IN POZNAN, CH. 27

Channel 27	A	B	C	D
Rooftop	-43.57 dBm	-45.15 dBm	-41.07 dBm	-42.99 dBm
2nd floor	-68.17 dBm	-66.22 dBm	-64.37 dBm	-62.63 dBm
1st floor	-72.28 dBm	-69.79 dBm	-71.85 dBm	-72.94 dBm
Ground floor	-77.30 dBm	-77.22 dBm	-75.96 dBm	-75.32 dBm
Channel 27	**E**	**F**	**G**	
Rooftop	-	-	-	
2nd floor	-65.98 dBm	-60.13 dBm	-64.94 dBm	
1st floor	-72.29 dBm	-68.56 dBm	-67.27 dBm	
Ground floor	-72.64 dBm	-75.75 dBm	-76.37 dBm	

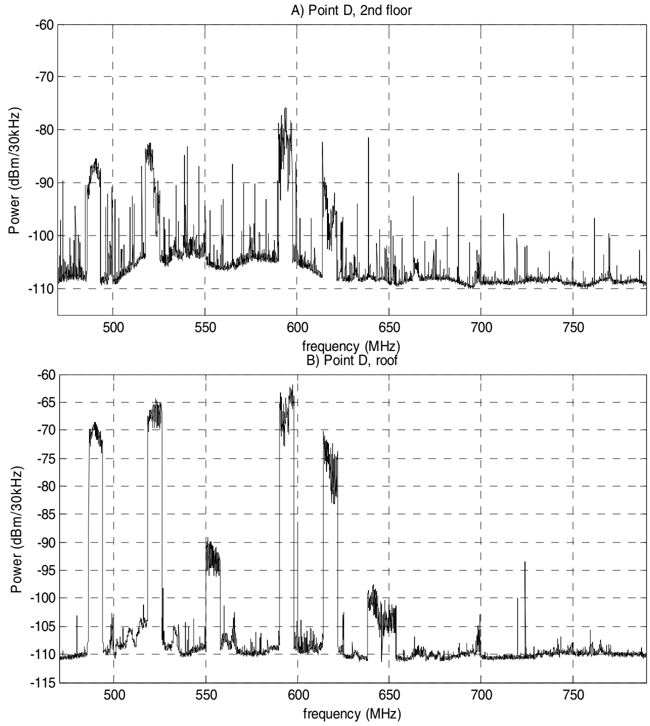

Fig. 4. Power spectral density of the TV Band in Poznan at point D: a) at the second floor, b) at the rooftop

2) Stability over time

Although the average received power in different locations of the building is an important factor, it does not illustrate the real behaviour of the signal since the averaging process of the received power smoothes the temporal variations of this parameter. Therefore the stability of the received power over time has been selected as the second figure of merit that has to be verified. The measurements have been performed in different day phases and repeated for different days of the week and for different durations. In all cases the observed results were very similar to those presented below, i.e. although the received power varies in time, these variations are small enough to allow us state that there is high stability of the received power over time regardless of the daytime. Exemplary plots for both Barcelona and Poznan campuses are presented in Fig. 5, where the non-averaged received signal samples are collected over 30 minutes. The difference between the PUT and UPC results are due to the differences of spectrum analyzers performance, i.e. the sweep time for the same RBW and VBW over one TV channel was longer in a case of the device used in Barcelona. However such a feature does not influence the overall observation, that the variance of the measured power is very low. Let us stress that the value of the power variance was always lower than 0.7dB, what allows us to state that for every TV channel there is a very little time variation of the received power.

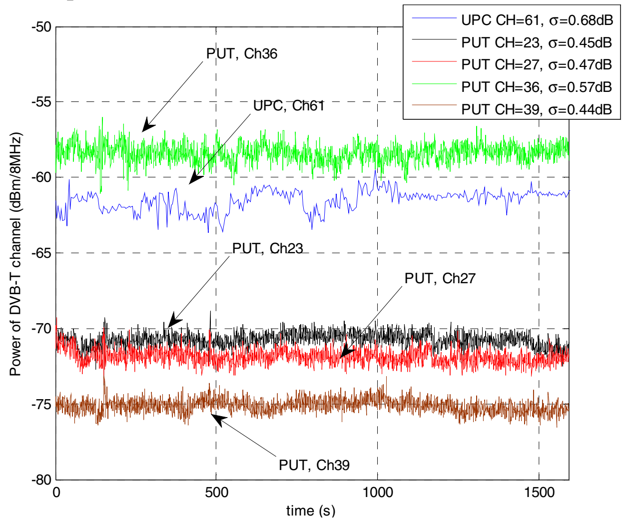

Fig. 5. Received power (non-averaged) observed over around 30 minutes

3) Crowded vs empty offices

Fig. 5 shown in previous subsection illustrates the changes of the received power as a function of time but in the situation where there were no or very few persons in the vicinity of the reception antenna. In order to be able to draw any reliable conclusions on the possible deployment of heterogeneous networks operating in TVWS, the radio environment maps have to take into account quotidian utilization of the premises (offices, class-rooms etc.). Therefore dedicated measurements have been performed in order to highlight the difference between crowded and empty offices. Analogous plot to Fig. 5 but for the crowded offices has been presented in Fig. 6.

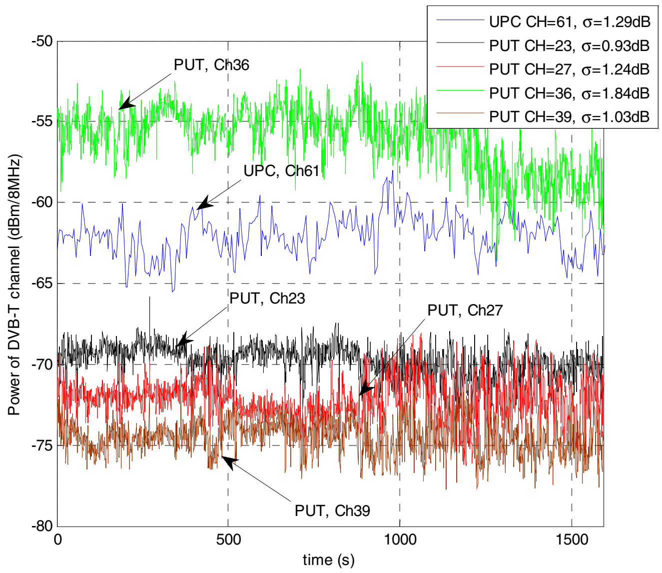

Fig. 6. Received power (non-averaged) observed over around 30 minutes – crowded premises

Comparison of these two figures bring us to the conclusion that the channel power is again quasi-stable in the sense, that the power variance has increased to maximally 1.8 dB. In general however, such an observation means that the quotidian usage of the premises does not impact on the stability of the received power. Similar results have been observed regardless of the place of measurements, i.e. if the reception antenna was located on the corridor or inside the offices or class-rooms.

4) Dependency on location

In the process of REM creation for the heterogeneous networks the influence of Doppler and multipath effects cannot be omitted. Clearly, in the case of static receivers or mobile terminals used inside the building the effect of speed can be neglected. Contrarily the influence of multipath phenomenon will play a crucial role. Thus dedicated measurements have been performed aiming at finding the relation between the received signal power and the location inside the building. For that purpose walk-tests have been done, in which the averaged power in the TV band has been measured every 30 cm (in case of Poznan) and every 40 cm (in case of Barcelona) along the corridor. Such a plot is shown in Fig. 7. One can observe that in both locations the variance of the measured signal was around 4-5 dB. In each point the measurement was averaged over 10 sweeps that decreased strongly the variance of samples coming from time domain (Fig. 5). Therefore, we can assume that all variations in received power are caused by the multipath effect connected with the location, and not with the time variations.

Furthermore, these measurements have been repeated in various days of the week in order to check the potential influence of quotidian usage of the building and surrounding area on the propagation conditions (Fig. 8). The overall conclusion is that the behaviour of the signal inside the building in the same positions is stable over time. Let us stress that the smoother shapes of the curves in that plot compared to Fig. 7 are due to the applied averaging procedure. In other words, the moving averaging function over 10 samples has been applied in Fig. 8. For this reason, the value at the current location takes into account also the measurements from the neighbouring locations, i.e. 3 meters.

5) Influence of walls

Finally, some post-processing of the collected data has been performed in order to illustrate the average influence of each floor on the received signal (Fig. 9). In other words, our goal was to measure the average attenuation (independent of the location and time, thus averaged over both location and time dimensions) observed at each building level. The attenuation shown in that figure is related to the power observed at the rooftop, thus one can conclude what is the influence of the given floor on the received signal strength.

Three main conclusions can be drawn: first, as expected, there is high relation between the received signal power and the location in the vertical profile of the building. Second, the solid green (with triangular markers) is much stronger than others and the reason for that situation is that this is the only one available SFN channel and the distance from the DVB-T transmitter is the smallest. Third, significant impact of the building construction is observed in the case of UPC, where the attenuation on the first floor is slightly lower than on the second floor (for each TV channel). In fact, in this case the transmitter is located at only 3.1 km from the building with almost line-of-sight conditions for all the floors (except the underground), meaning that the main attenuation comes from the wall penetration losses, which are similar for all the floors.

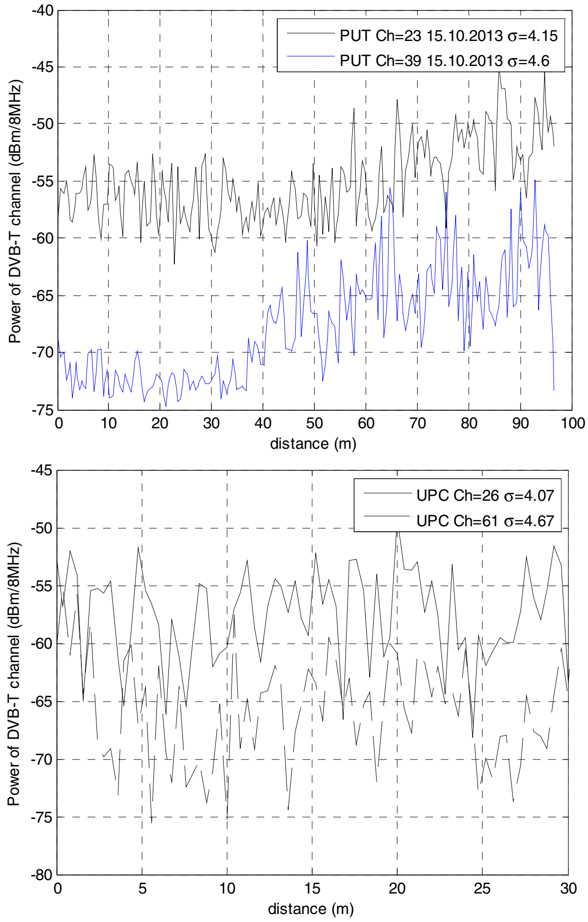

Fig. 7. Received power inside selected TV channel as a function of distance: in Poznan (upper plot) and in Barcelona (lower plot).

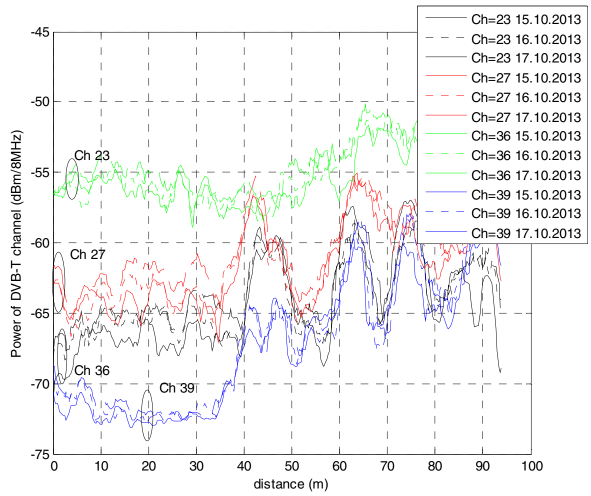

Fig. 8. Received power inside selected TV channel as a function of distance observed in various days

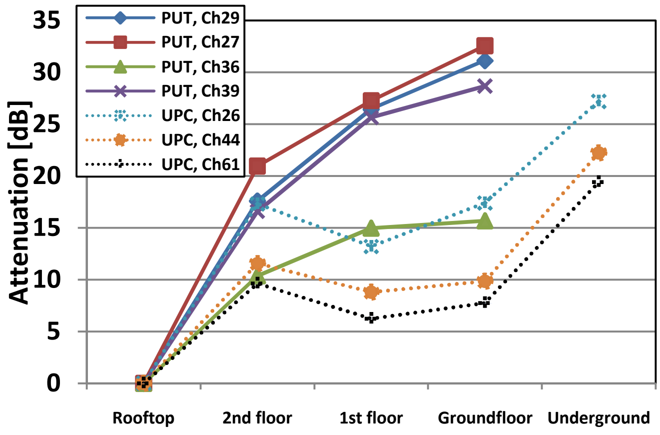

Fig. 9. Attenuation of the received signal power at different building levels relative to the power observed at the rooftop

V. Application to HetNets

Based on the presented results the following conclusions can be drawn which are important from the viewpoint of creation of detailed digital database (or REM) devoted for deployment of indoor TVWS small cells:

1. The received signal power in every TV channel is stable, observable variations over time in case of empty building were less than 0.7dB, and in case of crowded premises less than 2dB. Thus, there is limited influence of the quotidian usage of the building.

2. There are strong variations of the received signal power in terms of location (the variance was around 4-5dB). For the coverage measurements of DTV it is essential to average the received power over few neighbouring points.

3. The observations are repeatable; there is slight impact of the measurement phase (daytime, day of the week) on the obtained results.

4. High influence of the wall attenuation on the measurements is observed. There are much more degrees of freedom in new device deployment in the lower levels, while more protection will be required for higher levels.

Based on those measurements we can state that a reliable definition of a stable indoor digital map (location database or REM) is feasible, according to which maximum allowed transmit power of the new devices deployed inside the building can be obtained. Those values of transmit power of the femto access points, Wi-Fi hot spots, or mobile terminals etc. have to be calculated taking into consideration:

1. The characteristic of the particular small cell transmitter and its expected coverage area.

2. Required protection ratio indicated by the national regulators or international committees

3. Out-of-band radiations and amount of any harmful interference induced not only to the occupied TV channels, but also to the channels adjacent to them.

The fulfilment of all those requirements is feasible when the spatial distribution of the received power is known (at least approximated) and stable. Since the measurements presented in this paper prove this statement we can conclude that it is possible to perform more detailed measurements in various locations inside each building and use these measured and post-processed values for defining the indoor REM, which will be used for deployment of heterogeneous networks inside the building (i.e. access points of different kind, overlapping small cells etc.). It seems that due to high stability of the measured signal the necessity of frequent updates of such digital map will be significantly weaken, allowing for long-term deployment of the aforementioned transceivers.

VI. Conclusions

The goal of this work was to verify the existence of the opportunity for reliable creation of the indoor REMs that will be used for deployment of indoor heterogeneous networks. According to the obtained measurements one can state that the received signal strength is quite stable during the quotidian usage of the building, and the main variance is observed as a function of the location inside it. Nevertheless, one can state that it is feasible to construct such a map that will allow for reliable deployment of new transceivers inside the building and for coexistence of these systems. As a further step the calculation of the required protection ratio for a selected system and creation of such a map for both buildings is envisaged.

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