TVWS Indoor Propagation Model

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***Abstract* — The idea of efficient system coexistence in the so called TV White Spaces has attracted the researchers for many years. One of the recent research paths focuses on the application of such concept for the small-scale systems which can be deployed inside or around certain building. In this paper an analysis of the measurements is provided which were conducted in the premises of Poznan University of Technology in last quarter of 2015. The goal of these measurements was not to check the presence of the white spaces, but to model the TV white space transmission channel and propose an analytical indoor propagation model following ITU recommendations. Such a model can be used for faster deployment of indoor/outdoor secondary systems operating in the TV band.**

Keywords—TV white spaces, channel modelling, propagation model, indoor propagation

I. Introduction

One of the key challenges in designing new wireless systems and services is the lack of available spectrum that could be easily assigned for such purposes. This observation is particularly important in the context of 5G networks characterized by extremely demanding key performance indicators in terms of expected throughput, latency, number of connected devices or reliability [1]. Two main tendencies can be observed in the recent research directions – first option is to find wide ranges of unused frequencies in higher bands (starting from millimeter waves, but also higher bands are considered); second option concentrates on the flexible, yet efficient management and controlling of low-range spectrum currently occupied by the incumbent users. In the latter case, the problem of coexistence between the primary (licensed) and secondary (non-licensed) users appears immediately leading to the definition of advanced resource sharing strategies, such as LSA, SAS, or many others [2][3][4]. In that context, the potential of sharing of the vacated TV channels (existing as the result of the so-called digital switch-off of the analogue television) has been investigated by various researchers all over the world. It has been however stated that the application of TV White Spaces (TVWS) for long-range data transmission will be hard in practical realization.

As this observation is true, it is worth noticing that at the same time the future of wireless communication systems is being often associated with the small-cells, thus low-range communications. In that context the application of TVWS for, e.g., deployment of secondary indoor systems seems feasible. Numerous measurement campaigns have proved the validity of this concept – the amount of vacant frequencies for indoor communication is high (of course, depending on the particular geographical location) and – what is mostly important – rather stable in time. However, practical deployment of the secondary system modules will be simplified if the network planners could use dedicated channel models for indoor and indoor-outdoor communications. The goal of this paper is to propose such a propagation model based on the measurements conduced in the premises of Faculty of Electronics and Telecommunications at Poznan University of Technology in Poland.

In this extended abstract we show the analysis of the measurements which were carried out in November 2015. We start with the presentation of the measurement setup and the description of the building characteristics, followed by the brief discussion of the achieved results and proposed analytical model. In the final version of the paper the proposed analytical model will be described in more detailed way and compared with other models that can be found in the literature.

II. Measurement Setup

Our goal was to analyze the specificity of the indoor TVWS propagation channel, focusing on a) the relation between the received power and the direct distance between transmitter and receiver, b) on the influence of walls and ceilings. The whole measurement campaign has been carried out in the premises of the university, thus in order to exclude the influence of the people working there (students, researchers, teachers, etc.) the experiment has been conducted in the very late evening. Based on our previous measurement [5],[6],[7], we have selected one of the unoccupied TV channels (center frequency was set to 538 MHz) and setup the transmitter to send continuous OFDM signal with the transmit power of 10 dBm. As the transmit antenna used at the transmitter was omnidirectional (AOR DN753) with zero gain, the equivalent isotropic radiated power was also fixed to 10 dBm. Each OFDM symbol was generated using the IFFT of size 4096, where 3000 subcarriers were used for PSK-modulated data transmission (i.e., the subcarriers indexed from -3000 to -1 and from 1 to 3000 were used). The bandwidth of each subcarrier was equal to 2.03 kHz, resulting in the total occupied frequency band of 6.1 MHz. The sampling frequency was set to 8.333 MHz.

The selection of the way how the signal is generated [8] (i.e., selection of phase shift keying modulation format with iterative peak-to-average power ratio, PAPR, minimization) was made in order to meet the requirements of low time-variation of the transmit amplitude expressed by PAPR. According to [8], PAPR should be possibly low, and in our case it equaled 1.1056 dB.

The whole base-band and RF processing at the transmit side has been done by means of USRP platform equipped with the WBX daughterboard, connected to the omnidirectional antenna AOR DN753 via H155 cable. At the receiver side we used again the same omnidirectional antenna (in order to collect all of the possible rays achieving the point of measure) connected via H155 cable to the Rohde&Schwarz spectrum analyzer FSLv6. The analyzer worked in the so-called IQ mode (in-phase and quadrature samples were collected) with active preamplifier, and attenuation set to 0 dB. Measured attenuation of each H155 cable was equal to 0.25 dB. All of the reception modules (antenna connected to the spectrum analyzer and the computer used for storing the results) have been mounted on the dedicated trolley.

Once the received samples have been collected at the receiver, these were subject to correlation (in order to achieve time synchronization), carrier-frequency-offset (CFO) estimation and correction (in order to achieve frequency synchronization). After such processing, the signal-to-interference plus noise ratio was analyzed in the frequency domain considering every detectable signal replicas observed at the reception antenna with different time-shifts due to the multipath propagation [1]. Finally, the whole test sequence has duration of 36864 samples, what equals to around 4.42 ms.

III. Building Characteristics

All of the measurements have been carried out in the premises of the Faculty of Electronics and Telecommunications at Poznan University of Technology. As shown in Fig. 1, the building consists of three levels (including ground floor) and is an example of classical university/office building with equidistant windows on each floor. All walls – both internal and external – are made of concrete, and the doors to each room are from wood. The height of each level is of around 3.5 m.

Fig. 1. Building of Faculty of Electronis and Telecommunications at PUT, Poznan, Poland

The building is of L-shape (the middle outer corner of the building and left wing are visible in the figure above), and each wing of the building is of around 60 m long. The top view of the ground floor is shown in Fig. 2.

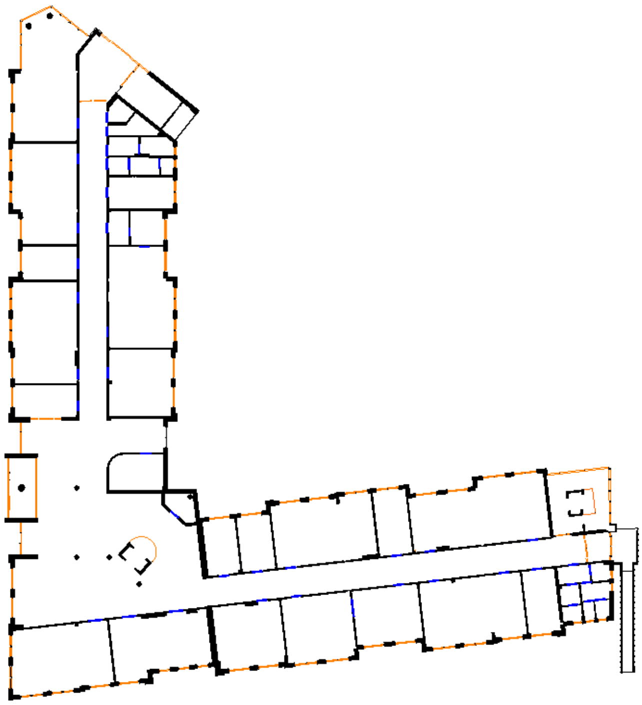

Fig. 2. Simplified top view of the groud flour (building of the Faculty of Electronics and Telecommunications)

The location of the transmitter was fixed in one room at the ground floor (please see the black diamond in Fig. 3); center of radiation of the transmit antenna was at the height of around 1.8 m. There were total 59 measurement points (equally distributed over all levels) identified on each floor of the building (please see Fig. 3). In order to average the fast-fading components, in each of the indentified points 100 separate measurements have been carried out. It has been achieved moving randomly the trolley with the reception equipment over the 1m wide square area. In the final analysis we take the median value of all collected measurements in a given location.

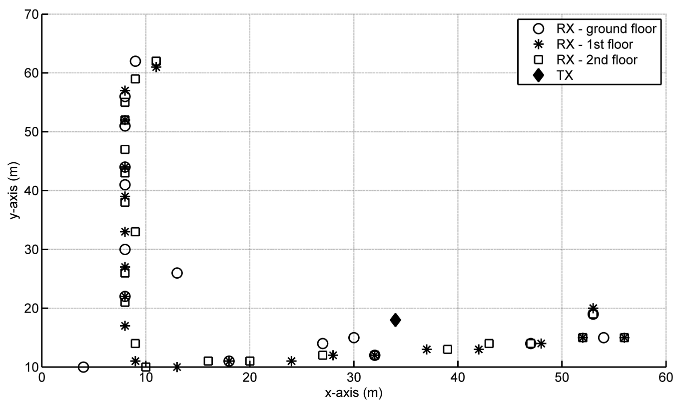

Fig. 3. Location of points of measure – a joint plot of all point from each floor. The (0,0) coordinates refer to the outer corner of the L-shape building, i.e. the corner between left and right wing.

IV. Achieved Results

First let us remind that one of our goals was to identify the relation between the received power and the direct-line distance from the transmitter to the receiver. We tried to answer the question, what will be the signal attenuation if we know the real direct-line distance between transmitter and receiver. Achieved results are shown in Fig. 4 together with the resultant linear approximation. The proposed approximation has been achieved in such a way that we tried to minimize the mean square error to the very generic and simple path-loss model $L=20*\log_{10}(f)+N\log_{10}(d)-28$, where f and d stand for the frequency in MHz and distance in meters, respectively. Based on the approximation we found that N=34.88. For such calculated value the average standard deviation from the simplified model is around 8 dB. Such high value of standard deviation leads us to the selection of more accurate generic model

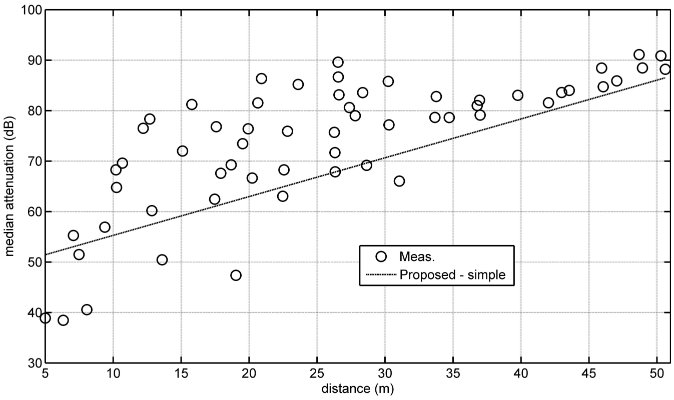

Fig. 4. Achieved measurement results in all 59 locations and the illustration of the proposed path-loss model.

As the model used in the first attempt is very simple, in the next step we tried to approximate the values in other reference model for indoor propagation, i.e., the one defined in ITU-R P.1238 [9]. This particular model considers in the path-loss calculation the total number of floors K through which the signal is propagating, $L=20\log_{10}(f)+N\log_{10}(d)+L_fK-28$. L_f stands for the measured attenuation of the ceiling. Based on our measurements we found that N=29.15, and L_f=7.15 dB. Achieved standard deviation of the measurement values from such a model is of only 5.61 dB.

In the next step we decided to compare our model with the one proposed by W. Yamada in [10], where the indoor propagation model for TV white spaces has been proposed. The authors proposed that the value of floor attenuation should be set to L_f=14dB. In such a case deviation equals 14.63 dB, and is rather unacceptable. Such a comparison is shown in Fig. 5. One can conclude that the detailed and accurate definition of the indoor and indoor-outdoor propagation model that will be independent from the structure of the certain building needs further investigation.

It is worth mentioning that the specific shape of the building (letter L) resulted in interesting behavior of the observed signal. It appeared that when the distance between the transmitter and receiver is higher than 32 m (i.e., this corresponds to the situation that the trolley moved to the other wing of the building) there was only little influence of the floor attenuation on the received power. The reason for this situation can be the fact that the dominating path is a direct one which does not lead along the corridors, but across the wings (i.e., the signals traverses the corner propagating from one wing to outside, and then enters the second wing). Thus the resultant attenuation is comparable regardless of the floor. Please have a look at Fig. 6, where the points of conducted measurements with distance greater than 32 m are highlighted in red. One has to verify also if this phenomenon could not be justified with respect to the remaining points.

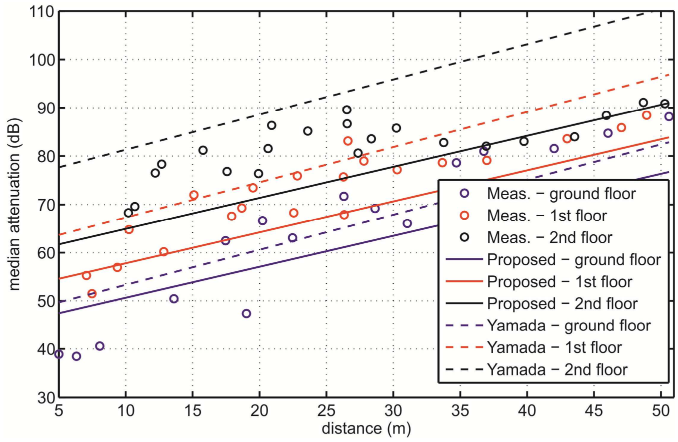

Fig. 5. Achieved measurement results in all 59 locations and the illustration of the proposed path-loss model including floor/ceiling attenuation

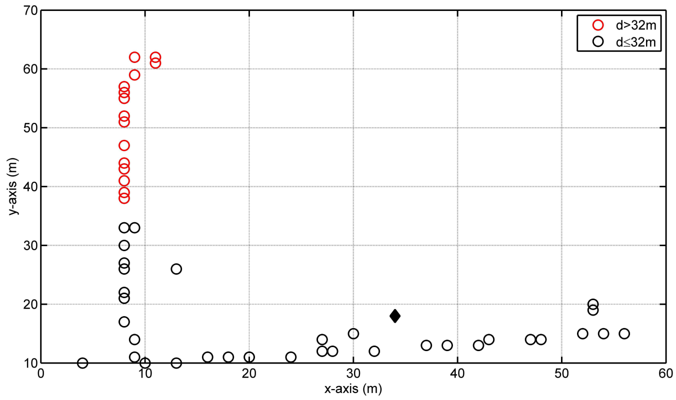

Fig. 6. Illustration of the points of measurements for which the direct path dominates in the received signal. Black diamond represents the transmitter.

Finally, the person responsible for network planning inside the building has to be aware not only of the propagation model, but also should consider the presence of ambient noise and interference. By saying ambient noise we think about all various types of noise observed by the receiver. Based on our measurements one can conclude that the changes in the observed ambient noise plus interference (we treat interference as noise) are very high. This is illustrated in the last figure, where the cumulative density function (CDF) of the measured noise and interference in every point of measure is presented. Two lines are shown there. First, the steepest, almost vertical line that represent the internal thermal noise of the analyzer. One can expect that in the device of that kind, i.e.

Rhode&Schwarz FSLv6 spectrum analyzer, the internal noise will be rather kept at the fixed level. The second line (solid) shows the distribution of the observed noise and interference. For 50% of samples the observed noise plus interference is of 4 dB higher than the internal noise. Moreover, the solid red line is not so steep, what means that the distribution of values of measured noise varies significantly as the function of location. From the perspective of practical deployment of white space devices it means that in some places the observed SINR is even 20 dB lower than in the others. In may happen that due to such strong SINR degradation the data transmission will be not possible in a certain locations. On the other hand, for many locations the equivalent, observed noise is only around 4 dB higher than the internal noise, what gives us the opportunity to consider such locations for white space device deployment.

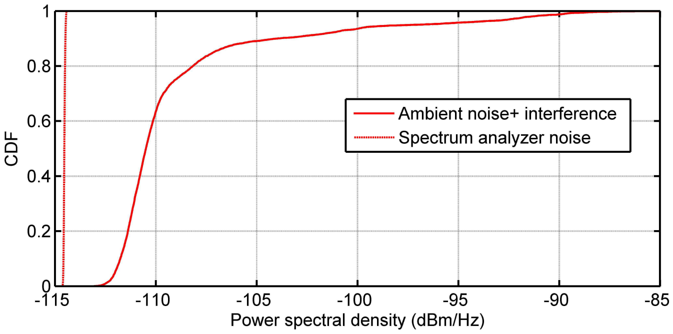

Fig. 7. Cumulative Distribution Function of internal noise of the spectrum analyzer and of the observed ambient noise and interference.

V. Conclusions

In this work we have shown the analysis of the measurements carried out in the premises of Poznan University of Technology. We have proposed the indoor propagation models, which by assumption are characterized by their simplicity. Nevertheless, the observed standard deviation is very low, proving the correctness of such approach. In the final version more detailed analysis will be provided together with the comparison of other solutions that can be found in the literature.

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