Spectrum occupancy in big cities – comparative study

Measurement campaigns in Barcelona and Poznań

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***Abstract*— In this paper a comparative study of two measurement campaigns carried out in Barcelona, Spain, and Poznań, Poland, to identify spectrum occupancy in different bands, is presented. In both cases the measurement setup was harmonized to obtain comparable results. The problem of efficient noise floor estimation was also considered and a pragmatic approach that takes into account both internal and ambient noise has been proposed. Obtained results show significant amount of unused spectrum, with similar results for both sites when analyzed globally (average spectrum occupancy of 27% in Poznań and 22% in Barcelona). On the contrary, when going to the detailed analysis of some specific bands, more relevant differences are obtained. These differences have been observed mainly in the Terrestrial TRunked RAdio (TETRA) bands that in Poland are also used by Code Division Multiple Access (CDMA) 450, as well as in the bands of theGlobal System for Mobile communications (GSM) due to the effects of Universal Mobile Telecommunications System (UMTS) refarming in the 900 MHz band.**

Keywords—spectrum occupancy; measurement campaign; Dynamic Spectrum Access; spectrum sensing

I. INTRODUCTION

The traditional approach of dealing with spectrum management in wireless communications is the definition of a licensed user granted with exclusive exploitation rights for a specific frequency and for a long period of time. While interference is easily avoided, this approach is unlikely to maximize the spectrum utilization, and in fact spectrum measurements carried out worldwide have revealed significant spectrum underutilization. As a result of this, regulatory bodies at international, European and national levels are actively working towards efficient and flexible spectrum regulation by fostering technology and service neutral spectrum management, spectrum trading and promotion of collective use of spectrum as well as shared use of spectrum through Dynamic Spectrum Access (DSA).

The shared use of primary licensed spectrum enables a more efficient use of spectrum without the need to change the current allocation [1]. It allows a secondary use of licensed spectrum with the condition that transmissions do not interfere licensed users (primary). In this context, achieving the necessary awareness of how the spectrum is being used in a certain area and which spectrum is available for secondary use becomes a key element. Different techniques have been proposed in the literature, relying on sensing concepts, on the use of geo-location databases and on beacons. However, there is quite general consensus that in the short term the use of geo-location databases is the technically most feasible approach for enabling secondary spectrum use. Just as an example, the Federal Communications Commission (FCC) eliminated the sensing requirement for secondary devices accessing the TeleVision White Spaces (TVWS) [2] and designated several database administrators for enabling the TVWS access while fulfilling the required constraints. In this direction, the so-called Radio Environmental Map (REM) has also been proposed as a knowledge database, constructed from spectrum measurements provided by different devices, used to dynamically store information related to the radio environment of wireless systems so that optimization in the use of spectrum resources can be achieved [3][4]. Under the above framework, achieving the necessary knowledge about the utilization of the spectrum in the different bands and locations is a very important aspect for an efficient exploitation of DSA. Depending on the nature of the primary license owners (e.g. Frequency Modulation (FM) and TV broadcasters, aircraft systems, defense systems, mobile phones, radars, satellites, etc.) very different characterization can exist, ranging from a very dynamic behavior with discontinuous transmissions in case of e.g. cellular bands to static use at local level e.g. in case of TV bands. In this respect, different spectrum measurement campaigns have been carried out worldwide [5]-[7], all of them revealing quite low spectrum occupancy rates and confirming the availability of frequencies for possible use in DSA. While all of these works have focused on measurements at specific locations, very few works have been published comparing measurement results obtained at different locations [8]. However, these comparisons are important to get a better understanding of the differences existing in the available bands throughout different countries, which can impact on deciding the most proper way to exploit each of the existing bands.

Based on the above, a first contribution of this paper is to present the comparison between spectrum occupation measurements carried out at two sites, namely Barcelona in Spain and Poznań in Poland. It is worth mentioning that the main purpose is to compare the overall occupation in the different bands of the two sites, but not to perform a detailed comparison over different periods of a day, week or year. In

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turn, another key aspect in any measurement campaign consists of properly estimating the noise power to identify which of the bands are free at a certain location. This is affected by both the internal noise at the measurement device and by the ambient noise (The main sources of ambient noise are imperfections of high power Radio Frequency (RF) devices operating nearby, e.g. local oscillator leakage, IQ imbalance, high order intermodulations, or other kinds of devices e.g. electrical engines or even some natural phenomenon, e.g. stars radiation.) The latter is location-and frequency specific and thus it needs to be extracted from the available measurements. In this respect, a second contribution of this paper is to present a pragmatic approach for estimating the noise power from the available measurements.

The remainder of this paper is organized as follows. First, Section II describes detection algorithms and the proposed approach for estimating the total noise level. The measurement setup is presented in Section III, while the comparative study of the measurements is provided in Section IV. Finally, Section V highlights the conclusions derived from this study.

II. Detection Algorithms – Pragmatic Approach

A. *Brief classification of spectrum sensing algoritms*

In order to assess the real spectrum occupancy highly-accurate spectrum sensing algorithms have to be applied. One can find various proposals in the rich literature [9], which in general can be divided into three classes. In the first set of spectrum sensing algorithms it is assumed that the sensing device has fast and reliable access to the detailed knowledge on the wireless signals possibly present in the considered frequency band. The classical example of such algorithm is the one based on the matched-filtering approach. In the second class the requirement on the detailed knowledge of the sensed signal is relaxed. The decision is based on the existence (presence) of a specific feature in the received signal, such as cyclostationarity characteristics. In the last class of algorithms the semi-blind analysis is possible, since only the information about the measured energy is required. All energy-detection based solutions are characterized by low complexity, but at the same time offer poorest efficiency expressed in terms of the so-called probability of detection and/or probability of false alarm, especially in low-Signal to Noise Ratio (SNR) regions. In order to cope with the problem of spectrum sensing weaknesses other approaches can be considered, such as application of databases or REMs [3]. In such a case, sensing performed by the single wireless terminals can be used e.g. for coarse estimation of the spectrum occupancy or for the purpose of updating the database entries.

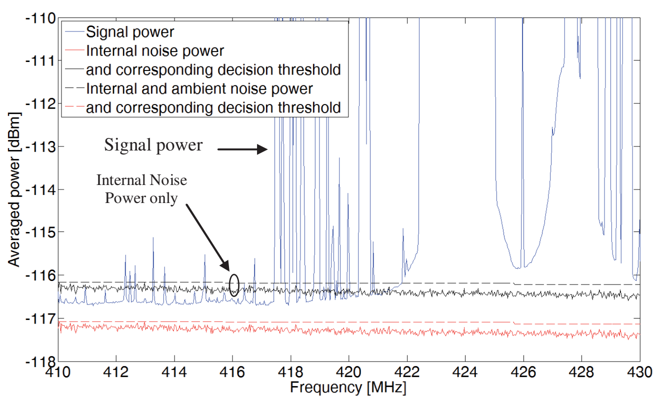

Fig. 1 Illustration of the difference between the classical and proposed calculation of the detetion threshold

Regardless of the used algorithm, the process of decision making on the vacancy or occupancy of the selected frequency band can be mathematically represented as the hypothesis verification. It is assumed that hypotheses H_1 and H_0 refer accordingly to cases where useful signal is or is not present in the considered frequency band. Thus, the aforementioned probability of false alarm P_{fa} describes the situation when the detection algorithm makes the decision on the presence of the transmission while in fact it does not exist, whereas probability of detection corresponds to the correct detection of the present signal. Based on the assumed value of the probability of false alarm and for the given noise power, the optimal decision threshold can be found analytically [10] for the assumed so-called Constant False Alarm Ratio approach.

B. *Pragmatic assessment of the noise variance*

One can immediately notice the main problem of correct and reliable estimation of the noise power. If the energy-detection based spectrum sensing will be performed, the only one type of noise that can be really measured in practice is the internal noise of the measuring device (e.g. spectrum analyzer, wireless terminal). Assuming the lack of any additional knowledge about the scanned frequency band it is theoretically not possible to distinguish if the received samples represent signal (particularly of low power) or ambient noise, e.g. the interferences or intermodulation products falling into the observed frequency band. However, such an approach (lack of ambient noise consideration) results potentially in high overestimation of the spectrum occupancy in the ranges of low frequencies, where typically high-power transmissions exist. Another problem that is associated with the correct estimation of the internal noise of wireless terminal can be drawn from the observation that in order to perform measurements the device should disconnect itself from the antenna using specialized switches or MicroElectroMechanical Systems (MEMS) elements. If one would like to avoid implementation of such modules the noise power measurements should be pre-stored inside the device and used later as the reference. However, additionally state of the device, e.g. age, temperature will have to be considered, thus huge amount of memory will be consumed. In order to cope with that problem we propose a sub-optimal approach, in which the local noise power (i.e. the power that corresponds to the considered frequency band) will be estimated based only on the observed samples. Knowing – first – the typical spectrum characteristics of the nowadays wireless signals, and – second – current regulations on the frequency allocation (i.e. the presence of the frequency gaps between the neighboring systems), we have assumed that, if the observation range of the frequencies is relatively high (e.g. 10MHz), and the observation time is long enough, with high probability at least one point in the observed averaged spectrogram will represent

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noise power. Let us notice that such an approach includes not only internal noise, but also ambient noise, what makes the reliability of the measured spectrum higher. After finding the smallest point in the calculated spectrogram, which with high probability represents noise power, its value is assigned as the reference for the whole 10MHz wide band. The difference between the classical theoretic approach and the pragmatic solution proposed in this work is illustrated in Fig. 1. Red and black solid lines represent the power (in dBm) of the internal noise and the corresponding detection threshold, accordingly. Dashed lines show, by analogy, the estimated internal-plus-ambient noise power and calculated detection thresholds. It can be observed that considering the effects of the ambient noise the threshold must be increased around 1 dB approximately. Notice that, in this way, significant part of the spectrum that would be erroneously detected as occupied with a threshold based only on internal noise, is now correctly detected as free. In the less occupied bands, where spurious emission is less common, the estimated noise power is nearly the same as the spectrum analyzer internal noise power.

III. Measurement Setup

This section presents the measurement setup that has been agreed to be able to compare the spectrum occupation in the two sites, namely Barcelona (Spain) and Poznań (Poland). It is composed of a broadband antenna that covers the frequency range from 75 to 3000 MHz connected to a high-performance spectrum analyzer. Moreover, to compensate for device and cable losses and increase the system sensitivity, a low noise amplifier is employed between the antenna and the analyzer. In particular, an external amplifier is used in the case of Barcelona while in case of Poznań the internal built-in amplifier of the analyzer has been used. In addition, in case of Barcelona, and due to the proximity of a broadcasting tower, very high power received signals existed in the measurement site that were causing undesired non-linear effects. Then, a filter to remove FM audio broadcast signals between 88 and 108 MHz has been used before the amplifier. In order to estimate the total noise, the methodology presented in section II has been used with P_{fa}=1%.

In Barcelona, the used antenna is the AOR DN753, which is a broadband discone-type antenna with vertical polarization and omni-directional receiving pattern in the horizontal plane. Moreover, the analyzer is the Anritsu Spectrum Master MS2721B that provides a measurement range from 9 kHz to 7.1 GHz, low noise levels, fast sweep speeds automatically adjusted, and various communication interfaces enabling the connection of external Universal Serial Bus (USB) storage devices as well as controlling instruments. The employed spectrum analyzer provides 551 frequency measurement points per span. Therefore, the frequency resolution depends on the widths of the measured bands. A 10 kHz Resolution BandWidth (RBW) has been selected which provides an adequate trade-off between the detection capabilities in time and data dimensions. In the measurements in Poznań, the antenna type is AOR DA-753g and the spectrum analyzer is R&S FSL6, considering a total of 95701 frequency measurement points in the same measured band and a RBW=30 kHz. Let us however stress that the performed measurements are in line with the ITU recommendation regarding spectrum measurements [11]. The location for the measurements in Barcelona was the roof of the Department's building in UPC Campus Nord (latitude: 41º 23' 20" N; longitude: 2º 6' 43" E; altitude: 175 m). This is a strategic location with direct line-of-sight to several transmitting stations located a few tens or hundreds of meters away from the antenna and without buildings blocking the radio propagation. This strategic location enabled us to accurately measure the spectral activity of, among others, a TV repeater, several nearby base stations for cellular mobile communications and a military headquarter as well as some potential maritime transmitters due to the relative proximity to the Barcelona's harbor. The measurements were done between November 2010 and February 2011, and they were conducted during several working days in time periods that include the busy hour. Analogously, the location for the measurements in Poznań was the rooftop of the Faculty of Electronics and Telecommunications of the Poznan University of Technology (52 º 24' 1.58" N, 16º 57' 21.06" E). This university building is very close to the big (and usually crowded) shopping center placed near the Malta lake which is famous recreation center in Poznań. Moreover, the main premises of the Poznań branch of the Polish national bank are placed in the closest vicinity of PUT. It is also worth mentioning that the big police station, and FM and TV transmitters are also located in the area of around 0.5km radius. The measurements have been carried out continuously during one week in February 2013.

IV. Results analysis

For many years huge effort has been put all over the world on the spectrum harmonization activities. Although many frequency bands have been assigned to the particular wireless systems, the final decision on the usage of the spectrum is obviously left to the national regulators and depends on the needs of the economy of the given country (i.e. the need for existence of selected systems). Such a situation can result in even significant discrepancy in spectrum allocation for different countries. This has been in fact observed in some of the measured bands in Poland and Spain, as illustrated in Figs. 2- 4, where the average received signal power is presented in three selected bands. In Fig. 2 the spectrum from 410-470MHz is shown. In Europe this frequency band is mainly devoted to TETRA systems. One can easily observe for both sites the big number of high power spikes which represent mostly the selected physical TETRA channels. However, in Poland also the CDMA450 technology is allowed in that band (412.25-415.00MHz and 452.525-457.00MHz for uplink, and accordingly 422.50-425.00MHz and 462.525-467.00MHz for downlink) which is reflected by the different pattern observed in these bands in Fig. 2b. These differences reflect that cognitive wireless terminals should possess highly detailed knowledge about the closest environment for performing DSA. Analyzing Fig. 2 one can also notice that the uplink channels (e.g. 410 to 420 MHz) are much less occupied than downlink ones (e.g. 420 to 430 MHz). This results from the fact that first, there is no broadcast channel in direction from wireless terminal to the base station, and second the user signals are of much less power than the ones generated by base stations. Similar observations to those obtained due to the

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analysis of the TETRA band can be drawn from the analysis of the GSM band shown in Fig. 4. Also here one can observe the presence of a strong UMTS signal in Poland, due to the refarming of UMTS in the 900 MHz band, while in Barcelona, UMTS900 was not yet in place at the time of performing the measurements and all the detected signals belong to GSM.

The comparison of the averaged received power in the TV band (see Fig. 3) allow us to state that there is much more vacant frequency bands in Poznań. Only four strong Digital Video Broadcast - Terrestrial (DVB-T) transmissions have been observed (one can also notice the fifth one of very small power in channel 43 localized around 650MHz). It also confirms that the achieved by us sensitivity is sufficient as only four DVB-T multiplexes should be available in Poznan. The 5th detected multiplex is probably designed for another part of Poland. In Barcelona the TV band is significantly occupied mainly due to the close distance between the UPC campus and the nearest TV mast and the presence of many local small TV stations. Such an observation proves that the amount of the white spaces in the TV band strongly depends on the wireless terminal location also at city level.

Finally Fig. 5 presents the average spectrum occupancy that has been obtained in different bands depending on the specific primary system. It is defined as the average duty cycle that has been obtained in the considered band, and it is computed by dividing the number of samples in which activity was detected with respect to the total number of samples for a certain frequency band. Three sets of measurements have been included. First two sets contain the spectrum occupancy results obtained for Barcelona and Poznań campuses, and are denoted as UPC and PUT-A. In that case the internal and ambient noise power has been used for detection threshold calculation. The third set of results, denoted as PUT-B, consists of the occupancy values obtained in the case where only internal noise of the spectrum analyzer has been considered while calculating the decision threshold. Comparison of the PUT-A and PUT-B scenarios illustrates the differences between the classical approach and the one (pragmatic) proposed by the authors. One can see that the differences in measured spectrum occupancy are rather slight (besides the range of low frequencies), and having look at Fig. 1 one can suggest that the real spectrum occupancy is rather closer to the results obtained for PUT-A. It is noticeable that the measured spectrum occupancy differs significantly between countries. It can be observed that the cellular systems are much more occupied in Poland. The reason for that situation can be the fact that the PUT campus is very close to the shopping gallery and is located near to the residential area, while measurement point in Barcelona is located in a rather residential area far from the commercial zone. Moreover, higher occupancy in the TETRA and Digital European Cordless Telephone (DECT) bands is probably the result of the fact that PUT campus is very close to the big police station and big national bank agency. One can however observe that in both countries the band around 1.4 GHz can be considered for the possible cognitive use, since it seems to be not overloaded. The overall spectrum occupancy when globally considering all measured frequency bands is equal to 22% in Barcelona and 27% in Poznań.

V. CONCLUSIONS

Proper and accurate knowledge about the spectrum utilization in time and space is a key requirement for the future introduction of DSA systems that allow a secondary use of licensed spectrum under strict constraints of not interfering the primary systems. In that respect, and while different papers in the literature have addressed individual measurement campaigns at different locations, this paper presents a comparative study of spectrum occupancy measurements carried out at two different cities, namely Barcelona in Spain and Poznań in Poland. For that purpose, the measurement setup has been harmonized to obtain comparable results. The problem of efficient noise floor estimation has been considered and a pragmatic approach able to capture both the ambient and the internal noise has been proposed and applied. Obtained results have revealed that similar occupations are obtained. However, when going to the details in some specific bands, relevant differences arise. Specifically, differences have been obtained in the TETRA bands that in Poland are also used by CDMA 450 and in GSM bands due to the effects of UMTS refarming in the 900 MHz band.

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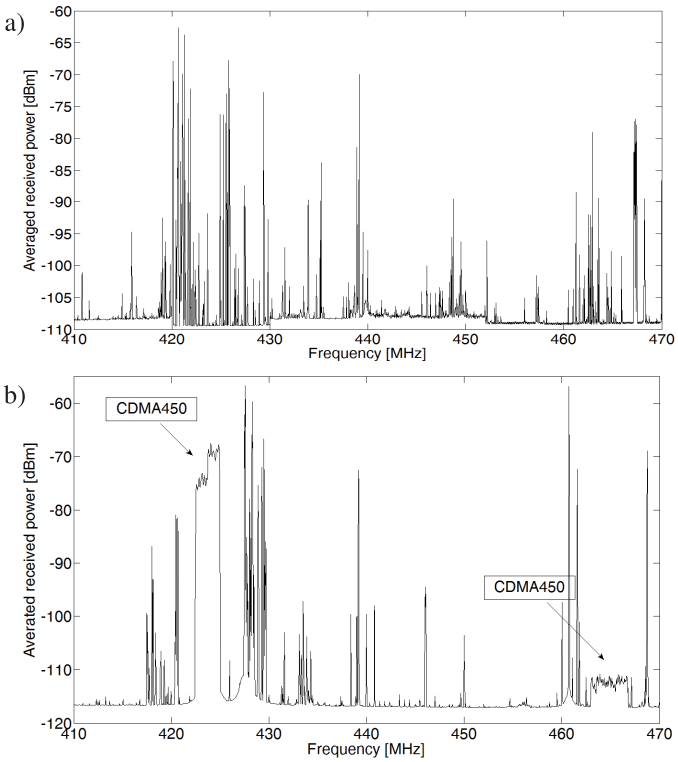

Fig. 2 Averaged received power in frequency band 410-470 MHz measured in (a) Barcelona (b) Poznań

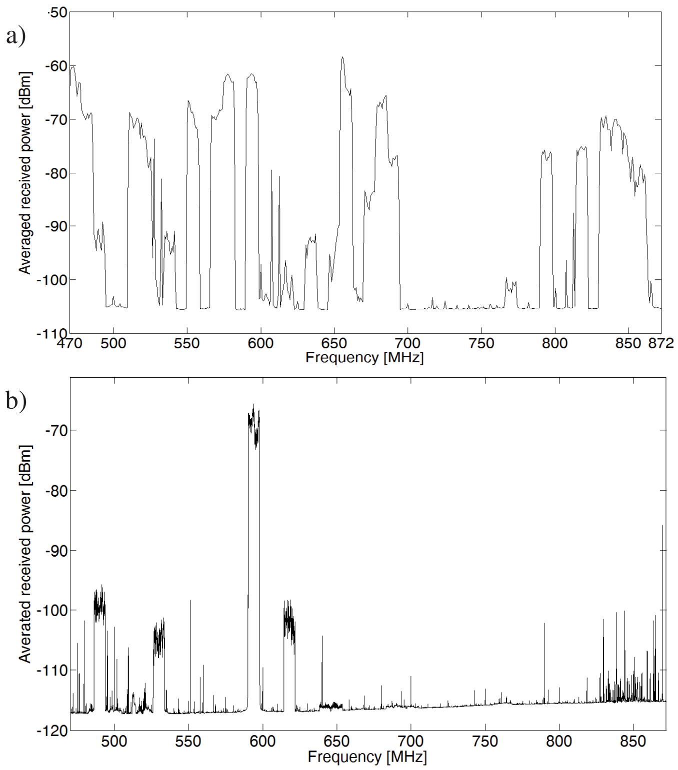

Fig. 3 Averaged received power in frequency band 470-872 MHz measured in (a) Barcelona (b) Poznań

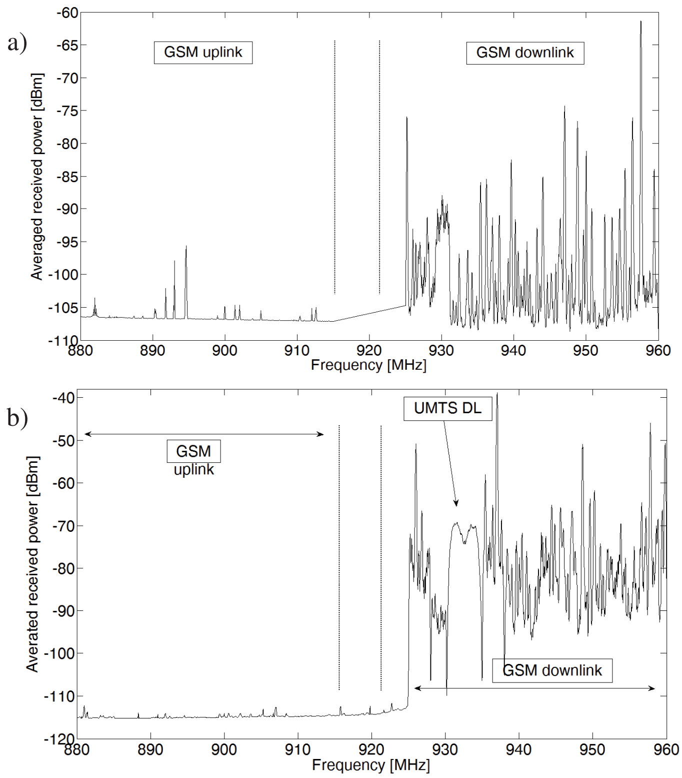

Fig. 4 Averaged received power in frequency band 880-960 MHz measured in (a) Barcelona (b) Poznań

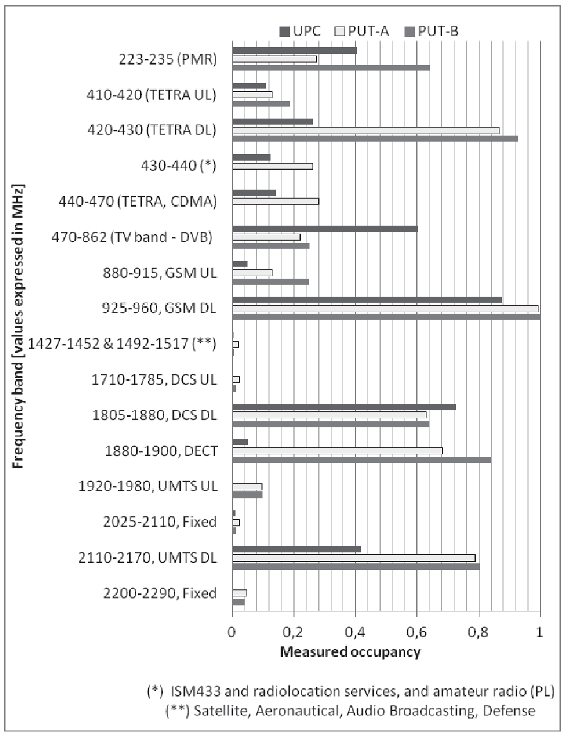

Fig. 5 Measured occupancy at Barcelona (UPC, dark bars), and Poznań: first case – effective noise includes both, internal and ambient noise (PUT-A, white bars), second case – only internal noise is considered (PUT-B, gray bars)

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