Detection Threshold for TVWS Spectrum Occupancy Determination in Urban Environments in Kosovo

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Abstract - It is known that determination of TV white space (TVWS) availability, in absence of geo-location databases, can be based on sensing and applying a detection threshold. In this paper we assess the availability of TVWS spectrum, using on site measurements in urban environment in Kosovo, obtained with NARDA SRM 3006 spectrum analyzer in the UHF and VHF bands. The measurement locations are chosen such as to represent various types of environments within the city of Prishtina. Results show that using a fixed low threshold setting for detection of TV signal presence, i.e., -95 dBm or lower, may heavily underestimate the TVWS spectrum potential. On the other hand, setting the threshold too high may result in misdetection of TV broadcasting, and potentially lead to harmful interference to the primary user. Thus, we propose an adjustable threshold-sensing algorithm to be implemented during data processing for spectrum availability determination. To improve the accuracy and have a more reliable picture of spectrum occupancy, we apply different sensing thresholds for different channels and use a double adaptive thresholding technique to enhance the performance of the detection mechanism.

Keywords - TV bands, UHF, VHF, measurement, sensing threshold

I. INTRODUCTION

The widespread use of wireless smart devices, such as smartphones, tablets and various other smart gadgets, has dramatically increased the demand for spectrum access. Adequate management of this prized resource has become a major issue, especially as a significant amount of literature on the topic has shown that a substantial portion of the frequency spectrum is in fact heavily under-utilized [1]. This fact is especially apparent in the frequency bands commonly allocated to TV broadcasters.

In this scenario, Cognitive Radio (CR) emerges as a promising solution as an enabling tool for the optimization of modern wireless networks and services. The operating principle of a CR system is based on allowing so-called unlicensed, secondary users to access to spectrum bands that are not being used, without interfering with the primary user who has the right (i.e., is licensed) to operate in a specific frequency channel [1].

The under-utilized portion of the TV bands is referred to as TV White Space (TVWS) and is of great interest due to the superior signal propagation characteristics. However, since the allocation and usage of TV bands can vary from country to country, an assessment of TV band utilization must be first performed to identify potential white spaces.

To do so, spectrum measurements need to be performed over the VHF band (174-230 MHz) and UHF band (470-860 MHz). In this paper we present the results from spectrum measurements over TVWS in Prishtina, the capital of Republic of Kosovo. Once the measurements are performed an assessment regarding the availability of the spectrum must be instigated. The simplest way is to compare the measured values to a predefined threshold. The design of the threshold, however, is an important task on its own. On the one hand, if set too low, it can easily underestimate the true availability of the frequency spectrum, while on the other hand, if set too high it can fail to detect the presence of primary users, colluding thus with one of the core principles of cognitive radio.

The assessment of spectrum availability, and therefore the design of accurate detection mechanisms, have been studied carefully in the literature. A comprehensive review on characterizing and modelling the availability of white spaces is provided in [2]. The estimation of the detection threshold without prior knowledge about signal and noise characteristics is addressed in [3]. The use of iterative algorithms based on impulse suppression principles for spectrum sensing purposes is proposed in [4, 5]. The authors in [6, 7, 8] propose instead the application of adaptive double thresholds to enhance the performance of sensing process. In our previous work [9], we also addressed the availability of TVWS, using a single fixed threshold, however as we argue in this work, a fixed predetermined threshold is not flexible enough to provide an accurate picture of the TVWS availability. In this work, instead, we adopt several of the techniques proposed in the literature and apply them to obtain an accurate and realistic overview of the spectrum availability in the TV bands, in the urban area of Prishtina, Kosovo.

It should be noted that TV broadcasting in Kosovo has not yet fully transitioned from analog to digital broadcasting, therefore the analysis presented in this work paints the current spectrum landscape in this country. Although our results show that spectrum availability already is substantial, it is expected that the amount of TVWS will further increase once the transition is completed [10]. This implies that repeat measurement campaigns, at the end of transition, will need to be conducted to calibrate threshold levels and draw availability maps, however, the methods for assessing the availability as well as setting the detection threshold,
TABLE 1. MEASUREMENT LOCATIONS

<table>
<thead>
<tr>
<th>ID</th>
<th>Location</th>
<th>Environment</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Faculty of Engineering</td>
<td>1.1. Ground floor/Inside</td>
<td>School/Residential</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2. Ground floor/Outside</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>RTK building</td>
<td>2.1. Ground floor/Inside</td>
<td>Urban/Residential</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.2. Ground floor/Outside</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Taukbahqe</td>
<td>Ground/Outside</td>
<td>Park</td>
</tr>
<tr>
<td>4</td>
<td>Vneshta</td>
<td>Ground/Outside</td>
<td>Park</td>
</tr>
<tr>
<td>5</td>
<td>KESCO building</td>
<td>5.1. Ground floor/Inside</td>
<td>Urban/High-rise buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.2. Ground floor/Outside</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.3. 12th floor/Inside</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.4. 12th floor/Outside</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mother Teresa boulevard</td>
<td>6.1. Ground floor/Inside</td>
<td>City centre</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.2. Ground floor/Outside</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Albi Shopping Center</td>
<td>7.1. Ground floor/Inside</td>
<td>Shopping centre/Outside of city</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.2. Ground floor/Outside</td>
<td></td>
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<td></td>
<td></td>
<td>7.3. 4th floor/Inside</td>
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<tr>
<td></td>
<td></td>
<td>7.4. 4th floor/Outside</td>
<td></td>
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<tr>
<td>8</td>
<td>Rruga B</td>
<td>8.1. Ground floor/Inside</td>
<td>Residential/High-rise buildings</td>
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<tr>
<td></td>
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<td>8.2. Ground floor/Outside</td>
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<td>8.3. 12th floor/Inside</td>
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<td></td>
<td></td>
<td>8.4. 12th floor/Outside</td>
<td></td>
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</tbody>
</table>

The rest of the paper is organized as follows: Section II describes the details of the spectrum measurement setup. The detection of spectrum availability and the various threshold setting mechanisms are described in section III. An overview on how the data collected during the measurement campaign was processed using the techniques described in Section III is provided in Section IV. Finally, numerical results are provided in Section V.

II. MEASUREMENTS SETUP

The analog terrestrial TV broadcasting in Kosovo is allocated in the following spectrum bands: VHF 174-230 MHz (8 channels, each 7MHz wide) and UHF 470 – 860 MHz (48 channels, each 8MHz wide), according to data obtained from Kosovo Independent Media Commission [11]. A list of TV transmitters, their coordinates, antenna height and transmit power are also provided in their website [11].

To assess the utilization of these bands in downtown Prishtina, measurements were performed at 8 different locations using the NARDA Selective Radiation Meter SRM-3006, using the spectrum analysis mode, a frequency resolution of 100 kHz, and sweep time of ~200 ms.

To account for losses from signal propagation, at most of the locations, measurements were performed both for indoor and outdoor environments. Measurement locations are listed in Table I.

The locations were chosen to represent the various types of environments present within the Prishtina urban area. Where possible, in areas with taller buildings, measurements were taken in the ground floor and higher floors.

As shown in Table 1, measurements were taken in three urban residential areas: at a school building (location 1) situated in an uphill terrain and partially shadowed; at a residential area near the city center surrounded mainly by low-rise buildings and little shadowing (location 2); and a residential area surrounded by high-rise buildings and shadowed by a hill (location 8).

Within the city center measurements were taken in two different locations: the main city boulevard (location 6), which is a pedestrian street surrounded by medium-rise buildings (4-6 stories tall); and at a high rise building in the city center (location 5), surrounded by lower-rise buildings and situated in an uphill terrain. Measurements were also taken at two different parks, one within the city itself (location 3) and the other one in the outskirts of the city (location 4).

III. DETECTION OF SPECTRUM AVAILABILITY

A. Problem Statement

In order to analyze whether a portion of spectrum is available or not, sensing is performed to detect the presence of a primary signal. If no signal is present, the portion of spectrum is considered as available. One of the most common approaches to detect the presence of a signal in a channel is to apply what is often called the energy detection technique [2,12]. In order to detect a signal applying this technique, the energy of the sensed samples is calculated and compared to a fixed pre-defined threshold. Its drawback is that it is very vulnerable to noise, which can lead to high rates of false alarms (the case of detecting a signal where there is none) or high number of misdetections (the case of not detecting a signal where there is one), depending on the threshold. While various sensing methods have been proposed in the literature [13], with different tradeoffs between required sensing time, complexity and detection capabilities, the energy detector has proven to be the most popular due to its simplicity, and the fact that it requires no prior information regarding the characteristics of the signal or the noise, which is most often the case. It is especially appropriate for the cases where only the power measurements of the spectrum under evaluation are available.

Given the values of the measured power level for the portion of spectrum under evaluation, the energy detector takes a binary decision, regarding the presence of a
primary signal. Let $P_n$ be the measured signal power. Then the classical detection problem can be expressed as [12]:

$$\delta = \begin{cases} 1 & \text{if } P_n > \gamma \\ 0 & \text{if } P_n \leq \gamma \end{cases}$$

(1)

where $\gamma$ is the predetermined detection threshold and $\delta$ is the binary decision variable. It should be noted, that the design of the detection threshold requires particular attention. If set too low, the detector will be biased towards detecting the presence of a signal, even when there is only noise, an event referred to as false alarm. A high rate of false alarms can lead to significant underestimation of the availability of the spectrum, rendering the process useless.

On the other hand, a high threshold, can underestimate the presence of the primary signal, i.e. TV signal, therefore increasing the risk of causing harmful interference to the primary user.

The goal is therefore to design a threshold such that it strikes a balance between the opportunistic potential of licensed bands and protection of the primary users, i.e. licensees.

B. Threshold setting

The most straightforward way to approach the threshold setting problem is to estimate the noise floor, or the mean value of the noise power. This can be significant task on its own, as it is shown that the noise level can change both as a function of time [12], and frequency [3]. In this paper we adopt the approach proposed in [3], also referred to as PFA method, as it does not require any a priori knowledge about the characteristics of noise. Assuming a sufficiently static situation, this method relies on estimating the noise level from samples that are known to be noise-only. The threshold is directly linked to the targeted probability of false alarm $P_{fa}$. Namely, once we set the desired $P_{fa}$, we find the threshold that our noise-only sample set exceeds with that probability. The values of $P_{fa}$ can be in range from $10^{-4}$ to 0.1 [3,12].

It is important to note that the noise level may vary with frequency [3], therefore the threshold should be estimated for each frequency bin or, at least, for each frequency channel.

1) Threshold adjustment applying FCME

The forward consecutive mean excision (FCME) algorithm originally proposed to suppress outlier samples in time domain [4], has also been applied in literature to detect narrowband information signals for spectrum sensing purposes [5]. Its appeal lies in its computational simplicity and effectiveness. Before the algorithm is started, the samples are sorted in ascending order, and a number of the lowest values (e.g. the 10% lowest values [4]) are included in the original clean set, denoted as $Q$. An initial threshold parameter, $T$, is also set using the expressions provided in [9]:

$$T = -\ln(P_{fa})$$

(2)

The procedure is further described in Fig. 1.

Once the two parameters are defined, the algorithm iteratively calculates the mean of the clean set:

$$\mu_Q = \frac{1}{|Q|} \sum_{P_n \in Q} P_n$$

(3)

where $|Q|$ is the cardinality of $Q$. In each iteration the rest of the samples are compared to temporary threshold $T_{temp}$, and included in the clean set $Q$ if they are below the threshold. The algorithm stops once there are no more samples to be included in the clean set. The final threshold is set to the temporary threshold of the last iteration, $\gamma = T_{temp}$. The FCME algorithm is quite fast and in our simulations typically converges in 3-4 iterations.

As the authors in [5] note, (2) is derived assuming the noise exhibits, at least approximately, a Gaussian distribution, which is a reasonable assumption if there is no prior knowledge about noise characteristics. If the nature of noise in known, (2) can be adjusted accordingly.

Also it should be noted that in case the samples are compared in logarithmic scale [dBm], then $T$ should also be converted to logarithmic scale, i.e., $T_{db} = 10 \log_{10}(-\ln(P_{fa}))$.

C. Detection using double adaptive thresholding

In addition to properly setting the detection threshold, several papers have also proposed using double thresholds to improve the detection process [6, 7]. The idea is to apply a lower and an upper threshold, namely $\gamma_l$ and $\gamma_u$, both of which can be derived independently using the PFA and FCME techniques. The detector works as follows: if the measured samples are above the upper threshold, then a signal is detected; if the samples are below the lower threshold, then no signal is detected. If the samples are
between the two, then further processing is required. The detection problem is then converted to:

$$\delta = \begin{cases} 
1 & \text{if } P_n > \gamma_u \\
\text{apply clustering} & \text{if } \gamma_l < P_n \leq \gamma_u \\
0 & \text{if } P_n \leq \gamma_l
\end{cases}$$

An additional step is therefore required to reach a definite decision when measured samples are in the ambiguous region. In this work we follow the examples of the authors in [6, 12], and apply a simple clustering technique to make a final decision. Initially all decisions in the ambiguous region are assigned “1”s. Then the decisions are clustered so that any gap within a cluster smaller than 3, is disregarded. Namely, say the decisions for each frequency bin in a frequency channel are as follows: “11110111001”. Because none of the gaps between the “1”s, are bigger than two, the sequence is transformed to “111111111111”. Finally, a cluster of “1”s is considered as “1”, only if at least one of the samples in the cluster exceeds the upper threshold. If not, the samples are considered noise.

IV. ANALYSIS OF MEASURED DATA FOR TV BANDS IN KOSOVO

In this section we analyze the data collected during the measurement campaign described in Section II. Availability analysis of TV band spectrum using a single fixed detection threshold has been a topic of our previous work [9]. Previous analysis showed that indeed using a low threshold, could vastly underestimate the availability of the spectrum, while a high threshold risked misdetection of primary signal.

At every location, the measurements were conducted inside and outside, and at different floors where applicable. Since we also have the list of active TV transmitters [2], we were able to calculate the distance between each transmitter - location pair, and identify for each location whether it falls under the service area of any of the transmitters.

The received power was measured in dBm over the entire TV band, in bins of 100 kHz. We denote the power received in bin $b$ of channel $c$ as $P_{b,c}$. The power levels detected in the individual bins within each channel band can then summed to obtain the received power level at the specific channel:

$$P_c = 10\log_{10} \sum_{b=1}^{B_c} \frac{P_{b,c}}{10^{9/10}}$$

where $B_c$ is the number of bins in channel $c$. Note that $B_c$ depends on the channel bandwidth and can vary from channel to channel.

Measurements were performed even in those channels that do not have active transmitters, according to the official list of TV transmitters [11]. These measurements were used to estimate the frequency dependent noise floor. The noise floor for active channels was then extrapolated from the obtained values.

A. Per bin vs. channel wide thresholds

The described techniques for threshold setting can be applied both at the bin and channel level. A per bin threshold implies that each bin value will compared to specific bin threshold. Our analysis shows that threshold variations within a channel are small, and indeed the per bin thresholds could be replaced by a single channel-wide threshold. When applying a single threshold method, decisions can be taken either at the bin or channel level. When decisions are taken at the bin level, by applying either the per bin or the channel-wide threshold, the decisions are combined to take a decision regarding the channel availability. When decisions are taken at the channel level, the per bin thresholds are summed to obtain a single per channel threshold for detection.

When applying the double threshold method, decisions are taken at the bin level and clustering is performed as described in Section III.C on the obtained per-bin decisions.

V. NUMERICAL RESULTS

The numerical results, obtained through processing of measurement data with MATLAB software are shown in this section. It should be noted that the measured values are randomly split into two sets: the first set is used for setting the thresholds while the second set is used for evaluating the occupancy using the derived thresholds.

First we look at how the estimation of noise floor changes with the frequency according to the PFA method. In Fig. 2, we show the $Pr_{fa}$ curves for three different channels, namely channel 5, 32 and 65, which are inactive. The figure shows clearly that the noise floor estimate shifts to the right with increasing frequency (channel number). This implies that in order to keep a constant rate of false alarm, the noise threshold needs to be increased with frequency.

Next, we look at the estimation of the noise floor using the PFA method, applying $Pr_{fa} = 0.03$. In Fig. 3 and Fig. 4, we show the obtained per-bin and channel wide noise level values, for the VHF and UHF channels, respectively. The blue bars are the estimates obtained from noise-only channels (inactive channels), while the orange bars represent the noise floor values obtained through extrapolation for the active channels.

In Fig.5 and Fig. 6 we show the derived thresholds at the bin level using the FCME algorithm, with $Pr_{fa} = 0.03$, for VHF and UHF channels, respectively. Here we also note that FCME threshold increases with frequency, and tend to be slightly higher for active channels.

In the next figures we show the calculated occupancy ratios obtained by processing the evaluation set of the measurement data. First we compare the single threshold methods, by applying the PFA method and FCME method independently. We also differentiate between cases where the decision is taken at the bin level (denoted as per-bin), and the case where the decision is taken at the channel level (denoted as per-channel).
When the decisions are taken at the bin-level, channel decisions are made using the OR rule. When the decision is taken at the channel level, the channel threshold is calculated as follows:

$$\bar{\gamma}_c = 10 \log_{10} \sum_{b=1}^{B_c} 10^{\gamma_{c,b}}$$

where $$\gamma_{c,b}$$ is the channel wide per-bin threshold.

In addition we compare the above mentioned methods to the fixed threshold case, with $$\gamma = -85 \text{ dBm}$$.

According to the official list of TV broadcasters [2], 43% of channels are currently not active, therefore at any given location, occupancy should not be above 57%, which is not the case with the fixed threshold. Applying the adaptive techniques such as PFA or FCME, we can immediately see a drop in occupancy ratios, which we expect to be much closer to the reality. We also note that PFA in general provides higher values of occupancy ratio than FCME, indicating that it provides more protection to the primary user. It should be noted that both FCME and PFA were performed applying $$Pr_{fa} = 0.03$$.

Finally, in Fig.8 we compare between the single and double threshold methods. The double thresholds were calculated using FCME, and by applying $$Pr_{fa} = 0.01$$, for the upper threshold and $$Pr_{fa} = 0.03$$ for the lower threshold [7]. We note here that the double threshold shows positive occupancy ratios for all locations, and in general provides values higher than the single threshold method. This indicates that higher protection for the primary users is ensured. But more importantly, it also seems to provide more realistic values in those locations where other methods were not able to detect a signal at all (e.g., location 6 and 7). This is important, since we know that all chosen locations were inside/or close to the urban area of Prishtina, and are undoubtedly under the service area of at least 3 national broadcasters.
Although it has been shown that the application of adaptive thresholds improves the performance of the energy detector in low SNR regions [7], at this stage we cannot yet present the dependency of the performance of proposed algorithms with respect to SNR, since we only possess the measurements of received power level, and not the actual values of experienced SNR, which cannot be calculated without an accurate channel model.

**CONCLUSION**

Assessment of TV band utilization is an important step in identifying the so-called TV white spaces, which could potentially be opened up for opportunistic use. It especially becomes important when no geo-location databases are available for a specific area. In such cases, it is important to have in place detection mechanisms that would correctly estimate the occupancy and availability of the TV channels. Applying a single threshold during detection of TV signals, has been shown to be ineffective as it largely underestimates the availability of the TV channels. In this paper, we compare between different adaptive thresholds algorithms proposed in literature by applying them to TV band spectrum measurement data collected in the urban area of Pristina. Our results show that applying adaptive thresholds significantly improves the detection process, providing more realistic values. In addition, our results show that the occupancy ratio varies from 0 to 0.3. This implies that the amount of under-utilized spectrum in these bands is significant, and there is ample room for potential cognitive radio operations in TVWS in Kosovo. Future work is planned to extend the measurement campaigns over the entire territory of the country, to obtain a comprehensive picture of TVWS availability and potentially initiate the compilation of a TVWS database for Kosovo.

**ACKNOWLEDGMENT**

This work was supported by the “Co-existence of wireless cognitive heterogeneous networks in TV White Spaces” research project funded by the Ministry of Education, Science and Technology of Republic of Kosovo.

**REFERENCES**