Adaptive Threshold Setting for Determining Spectrum Occupancy in TV White Space in Thailand

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ABSTRACT

This paper presents the results of spectrum occupancy measurements carried out in three different locations in Thailand: the Pathum Thani province (suburban), Bangkok (urban), and the Mae Kasa sub-district (rural) in the Tak province using a low-cost spectrum analyzer based system to show the spectrum occupancy at UHF TV band for testing the feasibility of TV White Space (TVWS) technology. Furthermore, inaccuracy of fixed threshold setting while performing spectrum occupancy measurements is shown by comparing the data with the ground truth report from the National Broadcasting and Telecommunications Commission (NBTC). An adaptive threshold setting algorithm, namely, Forward Consecutive Mean Excision (FCME) is then applied for determining the performance while carrying out spectrum occupancy measurements. Additionally, the adaptive threshold setting is modified to improve the accuracy of spectrum detection making the resultant spectrum occupancy more reliable.

CCS CONCEPTS

• **Networks → Wireless access networks**;

KEYWORDS

spectrum occupancy, threshold setting, RFexplore, National Broadcasting and Telecommunications Commission (NBTC)

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1 INTRODUCTION

Spectrum has become a scarce resource in wireless communication systems due to the high growth in using of wireless services. The static allocation of spectrum regulation has led to the inefficient utilization of spectrum. The problem with static allocation is that there is high spectrum usage in certain frequency bands and very poor usage in some other frequency bands. The TV broadcasting band is one such band where the spectrum utilization is very poor. Several spectrum measurement campaigns reveal that TV broadcasting has one of the most unused spectrum in sparsely populated area, especially in developing countries [1, 11] where the unused spectrum in TV bands is called "TV White Space (TVWS)". To utilise these unused spectrum, Cognitive Radio (CR) technology has emerged as a possible solution allowing Secondary Users (SUs) to use the licensed band given that their usages do not cause any interference to the Primary Users (PUs). To detect unused spectrum in CR, one of the approaches is to allow each Wireless Sensing Device (WSD) to run a spectrum sensing algorithms to identify the status of the frequency band. A high accuracy and low complexity sensing algorithm are very crucial for WSDs to dynamically access to the TVWS. To decide if the spectrum is free, test statistics from the measurements are compared with the corresponding threshold levels. Thus, threshold setting is considered to be a very crucial task of CR. The problem with using a fixed threshold is that the threshold setting is fixed at a particular level which is highly dependent on noise. However, when sensing spectrum over a wide range of spectrum like in case of TV bands the noise level varies, setting threshold for one band may not be appropriate for other bands. Thus, the fixed threshold setting brings low accuracy in detecting signals. In addition, adaptive threshold adapts its threshold according to noise levels in different frequency bands autonomously.

2 RELATED WORKS

Initially, a number of spectrum occupancy measurement campaigns were carried out in the US using discone antennas, expensive high-end spectrum analyzer, and a laptop [4, 9]. Measurement campaigns using low-cost devices have been studied in [3, 10]. These studies make use of RFexplorer, which is a low-cost, handheld, RF spectrum analyzer for conducting their measurement campaigns. [1] surveys a number of TVWS spectrum occupancy measurements conducted in different countries. Almost all of the spectrum measurement campaigns carried out using a fixed threshold setting for determining whether the channel is busy or free. An adaptive threshold method based on the analysis of measurement data's statistic was proposed to calculate the spectrum occupancy of Global System for Mobile Communications (GSM) Uplink (UL)/Downlink (DL) band in Beijing [7]. The paper concludes that self-adjusting threshold level setting workload is reduced while maintaining the level of accuracy due to significantly less number of samples is required for processing the thresholds. Recently, a covariance-based channel sensing method was proposed, where the adaptive threshold is selected in an intelligent manner to minimize the probability of error with sufficient protection to PU [2]. However, the computational complexity of the proposed algorithm becomes much higher in the presence of re-sensing which might not be feasible for the case of WSD which requires quite a low sensing time. Their proposed method performs well under low SNR due to their assumption of simple Gaussian noise and the use of a complex algorithm. The concept of machine learning has been applied in threshold setting of CR in [5] where their threshold learning algorithm converges to the optimal threshold satisfying a given false alarm probability with, however, an impractical time required. Moreover, [5] assumes the value of mean strength of noise is of unit one, compared to a mean value of 5 when the primary user is present. We are more focused on the work where the threshold setting is not based on such assumptions. However, none of the work in literature attempts to make use of an adaptive threshold setting algorithm to actual measurement data obtained from a low-cost spectrum analyzer. In addition, to the best to the authors' knowledge, no TV spectrum measurements campaigns have been yet done. In this paper, we investigate the spectrum occupancy in the Pathum Thani city of Thailand using a low-cost spectrum analyzer based system under static measurement cases. Furthermore, we apply an adaptive threshold setting in our measurement data obtained and also propose an approach to improve the detection performances of the adaptive threshold setting.

3 SPECTRUM SENSING THRESHOLD

3.1 Fixed Threshold Approach

The fixed threshold method is widely used in many spectrum measurement campaigns. Usually, the threshold level is set at -100 dBm which is the rules of thumb or experienced value commonly used in measurements in the TV band. In order to determine if the channel is free the percentage of samples at that channel should be less than 80% as it is a suitable value for the spikes encountered while taking measurements. Similarly, if the channel is busy 20% of samples should be greater or equal to the threshold level.

3.2 Adaptive Threshold Approach

We use a Forward Consecutive Mean Excision (FCME) algorithm for an adaptive threshold setting. FCME algorithm is applied for the signal detection in each UHF band number [8]. The computation of threshold is based on a threshold parameter. The threshold parameter is calculated in advance making use of the statistical properties in the noise-only case which may be unknown and a desired clean sample rejection rate [6, 8].

The FCME algorithm begins by rearranging the samples obtained in the ascending order according to their energies [8]. The sorted n smallest samples are assumed to belong to the initial set. The initial set is assumed to be free of interference and the size of the initial set is set to about 10% of the total data size. This is done to ensure that the algorithm converges. The threshold for FCME is computed as

$$T_{\mathrm{h}} = \bar{x} T_{\mathrm{CME}}, \tag{1}$$

where

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} |x_i|, \tag{2}$$

is the average sample envelop of the initial set, N is the data size, and T_{CME} is the threshold parameter computed as

$$T_{\mathrm{CME}} = -\ln(P_{\mathrm{FA,DES}}), \tag{3}$$

where $P_{\mathrm{FA,DES}}$ is the desired clean sample rejection rate.

4 PERFORMANCE EVALUATION

We consider the frequency band from 500 to 800 MHz at the Asian Institute of Technology (AIT) located in the Pathum Thani (40km away from Bangkok city center). We base our evaluation within the AIT area since we can use the spectrum report provided by NBTC (Thai regulator) as a ground truth of our measurements. The number of busy channels along with the corresponding frequency bands in the Pathum Thani area from the spectrum report is summarized as follows: Channel numbers including UHF 26, UHF 29, UHF 32, UHF 36, UHF 40, UHF 44, and UHF 52, which correspond to 510-518 MHz, 534-542 MHz, 558-566 MHz, 590-598 MHz, 622-630 MHz, 654-662 MHz, and 618-626 MHz, respectively.

4.1 Spectrum Measurement Setup

TV spectrum measurement campaigns were conducted using a low-cost handheld device (i.e., under 100$), called RFexplorer (WSUB1G model) fitted with Nagoya NA-773 wide band telescopic antenna. This configuration can analyze the frequency range from 240 MHz to 960 MHz, which includes the upper portion of TV band and hence is suitable for our measurements. Although the RFexplorer can be used as an independent unit, it is used along with a Personal Computer (PC) running software called "Rfestatic[1]" for acquiring data and their subsequent analysis. In our measurement trial, we focus on two scenarios: "indoor measurement" and "outdoor measurement", while considering the antenna height as a key factor. In case of indoor measurement, the antenna is set inside the building while considering two locations; ground floor (approximately 1 meters height) and first floor (approximately 5 meters height). As for the outdoor measurement, the antenna is set outside building at the ground (approximately 1 meters height) and the rooftop of the building (approximately 15 meters height). These measurements are chosen as they represent possible locations where the TVWS devices are deployed. Due to the space restrictions, we show the simulation results only for the measurement carried out in Pathum Thani. However, Table 1 summarizes the overall TVWS obtained after the analysis for all areas.

[1] https://www.rootandadmin.com/index.php/2016/11/12/comment-installe-et-configure-rfestatic-sur-ubuntu/?lang=en

4.2 Characteristics of Fixed and Adaptive Thresholds

We first study the characteristics of fixed and adaptive threshold using FCME algorithm by measuring the TV spectrum of the indoor-ground scenario at our department building. The calculated threshold of different frequency channels (25-60) is presented in Figure 1. The values of FCME threshold adapts itself depending on the signal strength of received signal while the fixed threshold level is stationary fixed at -100 dBm for every channel. Clearly, using the same fixed threshold value for every channel is not sufficient as it could not capture the dynamic of the received signal.

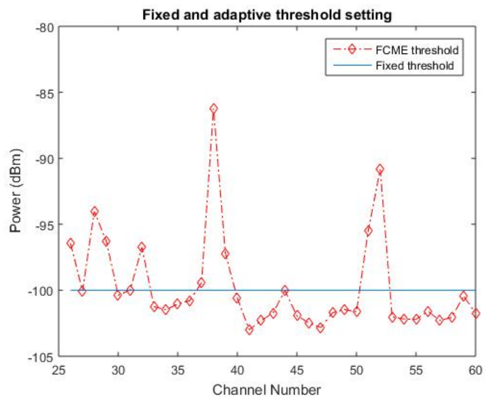

Figure 1: Comparing fixed and adaptive thresholds values with different TV channels

4.3 Impact of Adding Noise on FCME Adaptive Threshold

In theory, FCME requires at least 10% of additional white noise compared to the total samples of the received signal. To investigate this effect, we re-calculate the value of FCME adaptive threshold while varying the volume of added noise from 0% to 50%. Figure 2 and 3 shows the percentage of noise added on the busy channels and the value of threshold obtained for outdoor-rooftop and indoor-ground measurements. Percentage of added noise is gradually increased by 5% in each step. Since the noise varies differently across wideband of frequencies, therefore, in order to inject noise at a particular frequency band we can select the closest band which is free of PU signal. It can be clearly seen that as the percentage of noise added is increased, the threshold value decreases and beyond certain values of the percentages of the noise the threshold values would remain constant for all the four cases. For now, we choose 20% which is calculated manually after plotting the graph of the percentages of noise added versus the obtained threshold values. Notice that adding a large percentage of noise samples has also direct impact on the sensing time of the detector. It is required to have low sensing time with high accuracy for CR devices. Therefore, it is reasonable to find the optimal minimal value of the percentage of noise that can be added without sacrificing the performance of the CR device.

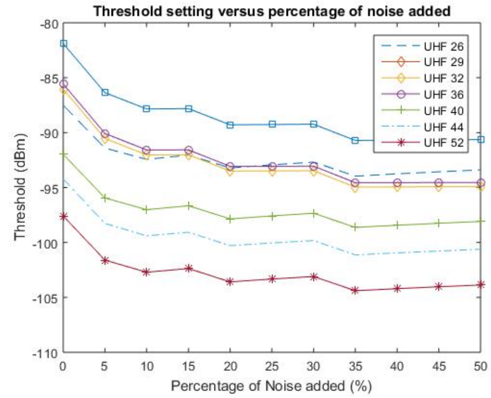

Figure 2: outdoor-rooftop

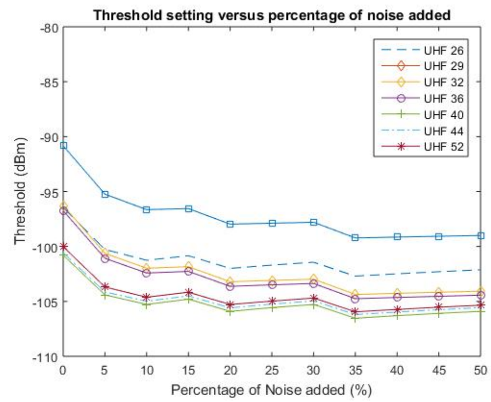

Figure 3: indoor-ground

4.4 Analysis of Error Detection

To analyze the accuracy of fixed and adaptive threshold approaches, we base our evaluation on the error detection of false alarm and miss detection indicators. The false alarm occurs when the detector decides signal is "busy" but the actual signal is "idle". On the other hand, the miss-detection indicates the more severe error in terms of interference as it occurs when the actual signal is being used ("busy") but the detector could not detect any occupancy ("idle"). Figure 4 shows the percentages of false alarm of 4 measurement scenarios. Clearly, there is no false alarm in case of FCME, and FCME with noise algorithms. This is because the thresholds for busy channels and for free channels are quite high. In contrast, the fixed threshold approach achieves 15% of false alarm detection in most scenarios, except the outdoor-rooftop which achieves 30% of false alarm detection.

Generally, FCME with noise performs better in terms of miss detection compared to FCME and a fixed threshold. As presented in Figure 5,the FCME with noise achives better performance than the fixed and FCME algorithms in terms of the number of miss-detection. The number of miss-detection is reduced up to 60% and 80% in comparison with the fixed and FCME algorithms respectively.

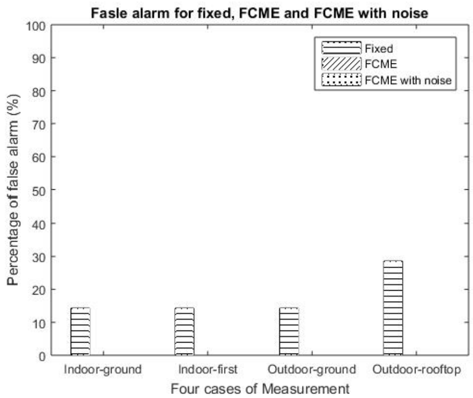

Figure 4: False alarm for four cases of measurements

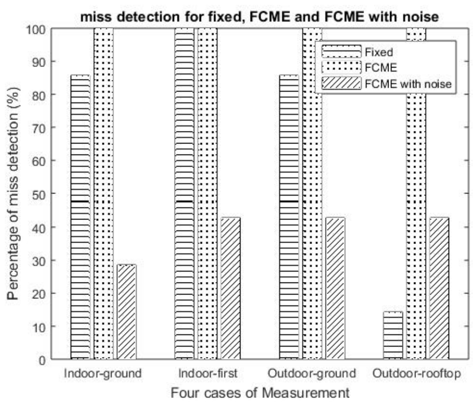

Figure 5: Miss-Detection for four cases of measurements

This shows the effectiveness of the FCME with noise algorithm in terms of miss-detection.

Intuitively, the FCME algorithm achieves 100% miss detection in all cases. This is because FCME requires at least 10% of added noise to better detect the availability of signal as mentioned in the previous section. However, in case of outdoor-rooftop, the fixed threshold achieves lower miss detection than the other twos. This due to the fact that the fixed threshold level is set at a higher value to allow for spectral leakages in sidebands caused by strong signal received outdoor.

In summary, the FCME algorithm is not yet optimized in terms of miss detection as it requires some level of added noise. However, after adding the 20% of noise, FCME can better improve the accuracy of spectrum detection as the percentage of false alarm and miss detection is relatively low compared to other approaches. Another interesting finding is that using fixed threshold is quite efficient in case of outdoor-rooftop measurement. However, it is not suitable for the indoor environment as it achieves very high miss detection number.

4.5 Exploring the Spectrum Availability in Different locations

We present the result of FCME with noise on spectrum availability in three locations. It can be seen from Table 1 that there are more white spaces available in Mae Kasa as compared to Pathum Thani and Bangkok. With the optimized FCME algorithm we were able to obtain all the white spaces seen in the NBTC report. This, however, was not achieved with the fixed threshold as seen previously.

Table 1: Spectrum availability in three different locations

Location	Idle Channel Numbers	Total White Spaces
Pathum Thani	27, 28, 30, 31, 33, 34, 35, 37, 38, 39, 41, 42, 43, 45, 46, 47, 48, 49, 50, 51, 53, 54, 55, 56, 57, 58, 59, 60	28
Bangkok	27, 28, 30, 31, 33, 34, 35, 37, 38, 39, 41, 42, 43, 45, 46, 47, 48, 49, 50, 51, 53, 54, 55, 56, 57, 58, 59, 60	28
Mae Kasa	26, 27, 28, 29, 30, 32 33, 34, 36, 37, 38, 40, 41, 42, 43, 44, 45, 46, 48, 49, 50, 52, 53, 54, 55, 56, 57, 58, 59, 60	30

5 CONCLUSION

The spectrum measurement results were analyzed to determine the spectrum occupancy using the fixed threshold value of -100 dBm showing that the TVWS band is highly underutilized. It is found that the use of fixed threshold has low accuracy in detecting signals in indoor environments and the use of the FCME algorithm as our adaptive threshold setting directly provided very low accuracy. Therefore, we have proposed to add noise in the received samples and then use the FCME algorithm for detecting signals. It is concluded that using this approach the miss-detection, and the correct rejection performances for indoor and outdoor environments become better than the fixed threshold. Finding an optimal value of the percentages of noise to be added is part of future work. Proposed work is carried out keeping in mind to improve the performance of small, mobile and low-cost spectrum analyzers (i.e., under 100 $), that are affordable in developing countries. TVWS has a lot of potential to provide affordable broadband access in rural areas due to its excellent propagation characteristics and abundance of spectrum availability in rural and developing regions. However, there are several challenges for use of TVWS, e.g. stringent requirement of the spectral mask by government agencies which contains many strict rules to apply for operating licenses.

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