SPECTRUM OCCUPANCY MEASUREMENTS BASED ON ITU-R SM.2256-1 RECOMMENDATIONS IN THE CONTEXT OF COGINITIVE RADIO

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Abstract

The recent popularity of wireless communication, has made the demand for radio spectrum to increase tremendously. Currently, most of the prime radio spectrum bands like the Ultra High Frequency (UHF) TV band are unavailable for any new applications. However, spectrum occupancy measurements done in a number of countries have shown low occupancy in the said bands. It is thus imperative, that if new approaches for accessing the radio spectrum are formulated and adopted, new applications could be accommodated in the existing prime radio spectrum bands. One such approach is the use of the cognitive radio. In Kenya, spectrum occupancy measurements have not exhaustively been done, and hence information on spectrum occupancy, which is a key enabler of cognitive radio, is not readily available.

This paper therefore presents results of spectrum occupancy measurements, carried out in an urban and a rural area in Kenya, in the UHF TV frequency band 470 MHz -694 MHz, in the context of cognitive radio. The spectrum occupancy measurements were carried out, and evaluated in accordance with the ITU-R SM.2256-1 recommendations, to allow results comparison from similar measurements carried out elsewhere. The choice of this band, is due to its good signal propagation characteristics. An active UHF omnidirectional antenna, in conjunction with a 9 KHz -3.2 GHz spectrum analyzer, were used to collect the spectrum occupancy data over a period of 12 hours, which was then processed in a MATLAB software.

The results obtained from the aforementioned measurement area, showed an average spectrum occupancy of 49.6 % in the urban area and 26.3 % in the rural area. Thus, about 50 % of the spectrum in this band is unutilized in the urban area, and 74 % in the rural area, and hence, could be used for cognitive radio applications, to ease the spectrum scarcity. The results obtained in this study, is in line with similar results presented in the literature.

Key words: Spectrum Occupancy Measurement, ITU-R SM.2256-1, Ultra High Frequency, Cognitive Radio

1.0 Introduction

With the increasing popularity of wireless/mobile mode of communication, the radio spectrum has become a scarce commodity in many countries. Most of the prime radio spectrum band for wireless communication has already been allocated to the existing services on exclusive basis. New wireless/mobile applications may not be accommodated due to unavailability of the spectrum (Communications Authority of Kenya, 2016). However, study has shown that the scarcity of the radio spectrum has more to do with the approaches used to share and access the spectrum as opposed to its over utilization. (Jide J.Popoola et al. 2016).

There is therefore need, for more innovative ways to allocate and manage radio spectrum to address this artificial shortage. The cognitive radio system is one such innovation (T.Y¨ucek and H.Arslan, 2009).

A Cognitive radio system (CRS) is defined as a radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained. CRS makes it possible for devices to use radio spectrum on opportunistic and secondary basis on condition that they don't cause harmful interference to the primary users (ITU-R, 2009).

According to Mastorakis *et al* (2011) an example of the Cognitive radio is the Television whitespace (TVWS) devices that operate in the Television (TV) band. Television White Spaces refer to frequency channels allocated on licensed basis, to TV broadcasters but which are not in use in a given place or time. Such un-occupied channels, could be used by the secondary users on opportunistic basis, for other applications such as for broadband internet, on condition that no harmful interference is caused to the primary user.

The amount of Television whitespaces varies from one country to another, one region to another and even in time. For the Television whitespace technology to be employed, there is need to ascertain the availability of the television whitespace spectrum in a given area. This is done through spectrum occupancy measurements in the TV band. The spectrum occupancy measurements have been done in several countries and showed low spectrum occupancy and hence availability of TV whitespaces. Some of these include those done by (A.Al-Hourani et al, 2015), (C.Kurnaz, B.Engiz and Z.Albayrak, 2016), (F.Kiftaro ,M.El-Tarhuni and K. Assaleh, 2017), (M.Cardenas et al ,2016), (P.Balina, K.Garg and S. Rao, 2014), (R.Aguilar, M. Cardenas, U.Pineda and E.Stevens, 2013), (S.Jayavalan et al, 2014), and (Y.Han , Y.Wen, W.Tang and S.Li , 2010) among others. In Kenya, spectrum occupancy measurements on the TV radio frequency band have not been done and hence no data is available in the literature. There is therefore need to carry out such measurements as a precursor to the deployment of the TV white space technology.

In most of the spectrum occupancy measurements in the literature, the authors used different techniques for spectrum occupancy measurements and evaluation. Some of the methods used include; Non-Stationary Hidden Markov Model (X.Chen, H.Zhang ,A.MacKenzie and M.Matinmikko, 2014), 20% root-mean-square and amplitude probability distribution methods (S.Ming, Q.Qing and X.Liu ,2014) and dynamic threshold computing method based on SOM Neural Network (M.Yang, H.Dai and N.Ye , 2014) among many others. This makes it difficult to compare the different obtained results. To address this challenge, the International Telecommunication Union-Radio Communication Sector (ITU-R) has recommended a standard method of carrying out the spectrum occupancy measurements and evaluation under the Report (ITU-R) SM.2256-1 (ITU-R, 2016).

In this paper, we present the results of spectrum occupancy measurements based on the recommendations of the ITU-R SM.2256-1 report, carried out in the radio frequency band 470 MHz - 694 MHz, which is the band allocated to digital terrestrial television broadcasting in Kenya (Communications Authority of Kenya, 2016). The measurements were conducted in Juja town, Kiambu County which is an urban area and in Naaro village, Murang'a County which is a rural area, with an objective of determining the availability of vacant TV channels that could be used for television whitespace applications.

The spectrum occupancy was determined by comparing the received signal level to a certain detection threshold based on the noise power of the spectrum analyzer. The results obtained from the spectrum occupancy measurements, are expected to justify the deployment of TVWS devices for secondary applications, like the provision of the broadband internet.

The rest of this paper is organized as the following, in Section II we provide a detailed explanation of the measurement setup, and how the raw measurements are post-processed, in Section III we present the measurement results. Finally, we provide conclusion remarks in Section IV.

2.0 Measurement Equipment and Methodology

The main tool in our measurement setup is the Rigol DSA832E Spectrum Analyzer having a range of 9 KHz to 3.2 GHz. The spectrum analyzer is connected to an active Ultra High Frequency (UHF antenna mounted on top of tall buildings clear of any obstruction. The setup is interfaced via Ethernet port to a laptop equipment running MATLAB. The measurements for the range 470 to 694 MHz were taken using Power Avg trace type, which displayed the average of data from multiple sweeps of each point of the trace. These results were stored in a removable flash disk as csv files, showing the measured frequencies in hertz and the corresponding signal amplitudes in dBm.

In Figure 1, the diagram of the setup is illustrated, and in Table 1, the measurement parameters are summarized. The measurements were conducted in two sites in Kenya, one being in an urban area while the other in a rural area. For each of the site, the measurements were taken for period of 12 hours between 0600 Hours to 1800 Hours. Two types spectrum occupancy measurements were carried out in each site, namely the frequency channel occupancy and the frequency band occupancy, results of which were then compared (ITU-R, 2016).

Figure 1: Measuring Equipment setup

Table 1: Measurement Parameters

Parameter	**Value**
Spectrum analyzer Frequency range	9 KHz to 3.2 GHz
Measurement frequency range	470 MHz to 694 MHz
Resolution Bandwidth	1 MHz
Sweep time	1.20 ms
Noise floor (Average)	-135.00 dBm/Hz
Detector type	Positive peak
Trace Type	Power Avg
Threshold value	-68.2dBm
Antenna Polarization	Vertical
Measurement duration	12 hours per site

2.1 Noise Analysis and Detection Threshold

The threshold is a certain level at the receiver input that determines whether a channel is considered to be occupied (ITU-R, 2016). It may be a fixed, predefined level or a variable level. The resulting occupancy greatly depends on the threshold. It should be low enough to enable detection of all signals that would be usable by a commercial receiver at that location, but setting it too low would result in phantom emissions that are in fact not present. To set the threshold value we needed first to measure the noise level.

A frequency band that was free of wanted and unwanted emissions near the 470MHz – 694 MHz band was identified for purposes of noise measurement. The noise measurement was done with the same settings (measurement time and bandwidth) as used for the actual occupancy measurement. The noise level was measured once and the result was used for the whole occupancy measurement since all channels to be measured were relatively close to the frequency of the band used for the noise measurement. The final threshold of the occupancy measurement was set 4.5dB higher than the measured noise level. This was to protect against short-term peaks in the noise level which would otherwise l result in phantom occupancy.

2.2 Frequency Channel Occupancy measurement

Frequency Channel Occupancy (FCO) is the measurement of individual TV channels to determine the degree (percentage) of occupancy of these channels.
A frequency channel is occupied as long as the measured level is above the threshold. For one channel, the FCO is calculated as follows:

$$FCO = \frac{N_0}{N} \tag{1}$$

where:
N_O: number of measurement samples on the channel concerned with levels above threshold
N: total number of measurement samples taken on the channel concerned during the integration time.

2.3 Frequency Band Occupancy measurements

Frequency Band Occupancy (FBO) is the measurement of a frequency band, specified by start and stop frequency, with a step width that was smaller than the channel spacing, to determine the degree of occupancy over the whole band. A step width of 373 KHz was used in this case.

The occupancy of a whole frequency band counts every measured frequency and calculates a total figure in percent for the whole band, regardless of the usual channel spacing. The number of measured frequencies determined by the frequency resolution was higher than the number of usable channels in a band. If the measurement time of each sample is equal, the FBO is calculated as follows:

$$FBO = \frac{N_0}{N} \tag{2}$$

where:
N_O: number of measurement samples with levels above the threshold
N: total number of measurement samples during the integration time.

A. Spectrum resource occupancy

Spectrum Resource Occupancy (SRO) is the ratio of the number of channels in use to the total number of channels in a whole frequency band.
For the case of the frequency channel occupancy measurement, the SRO was calculated as follows:

$$SRO = \frac{N_0}{N} \tag{3}$$

where:
N_0: number samples on any channel with a level above threshold
N: total number samples taken on all channels during the integration time.

For the case of frequency band occupancy measurement, the SRO was calculated as follows:
First, the channel occupancy was calculated from all measurement samples.
Then, SRO was calculated according to the FCO:

$$SRO = \frac{N_{och}}{N_{ch}} \quad (4)$$

where:
N_{OCh}: number of samples on center frequencies of any channel with levels above threshold
N_{Ch}: total number of samples taken on center frequencies of any channel during the monitoring duration.

3.0 Spectrum Occupancy Measurements Results and Discussion

3.1 Noise Analysis and Threshold value

Through spectrum occupancy measurements within the measurement sites, the radio frequency band 455 MHz to 470 MHz was found to be free of wanted and unwanted emissions. It was thus used for the measurements of the noise level, due to its proximity to the band of interest. The highest noise level was found to be -72.7dBm as shown in Figure 2. The threshold value was set 4.5dB higher at -68.2dBm.

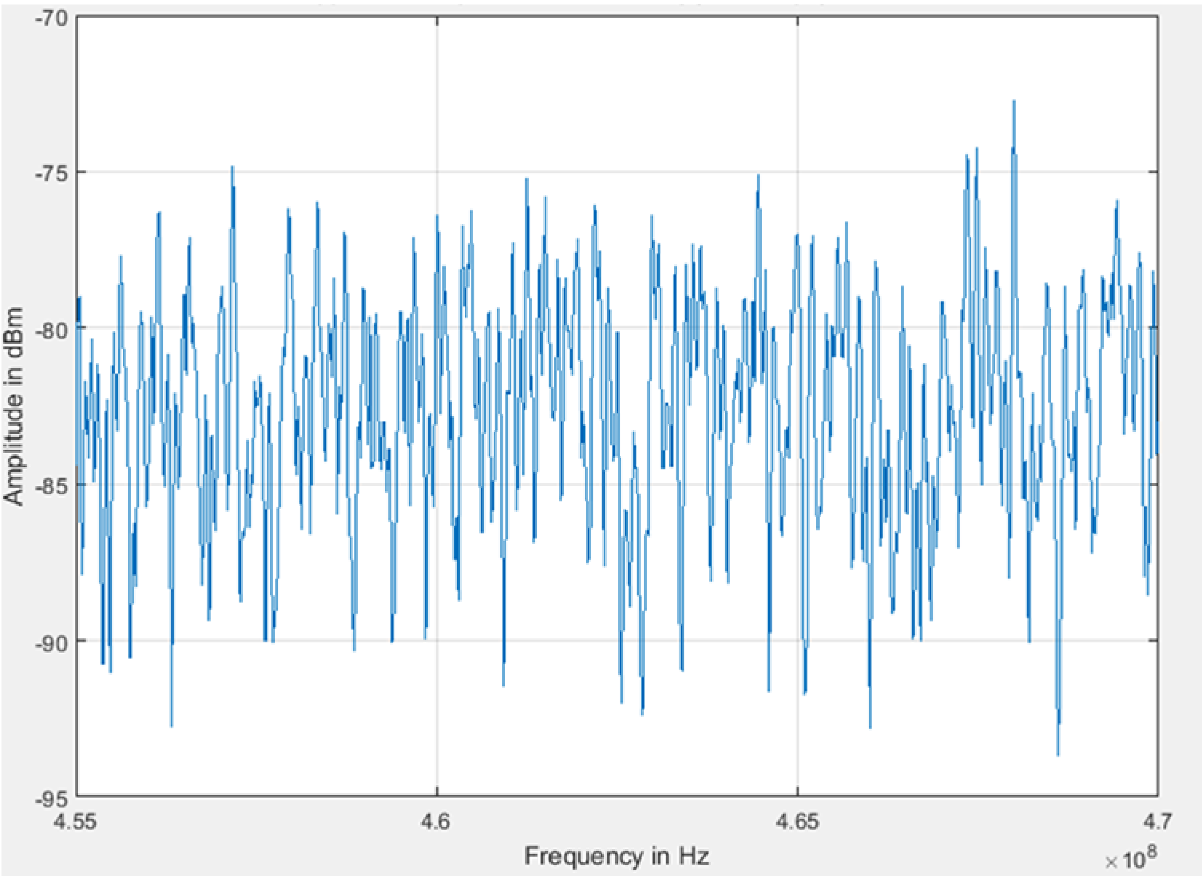

Figure 2: Noise Level Measurements in the band 455MHz to 470MHz

3.2 Frequency Channel Occupancy measurement results

The Table 2 show the number of occupied and un-occupied channels. The Television channel bandwidth is 8 MHz wide. From the results it could be seen that in urban area the spectrum resource occupancy is 50% while in the rural area it is 26%. The Figure 3 and Figure 4 show the distribution of the channels occupancy in the urban and rural areas respectively. It was noted that the occupancy or un-occupancy of a channel remained constant throughout the monitoring duration. This could be justified by the fact that; the television broadcasting transmission status does not change regularly.

Table 2: The Frequency Channel Occupancy

Area	Total Channels	Occupied Channels	Un-occupied Channels	% of Occupied Channels	% of Un-Occupied Channels
Urban	28	14	14	50%	50%
Rural	28	7	21	26%	74%

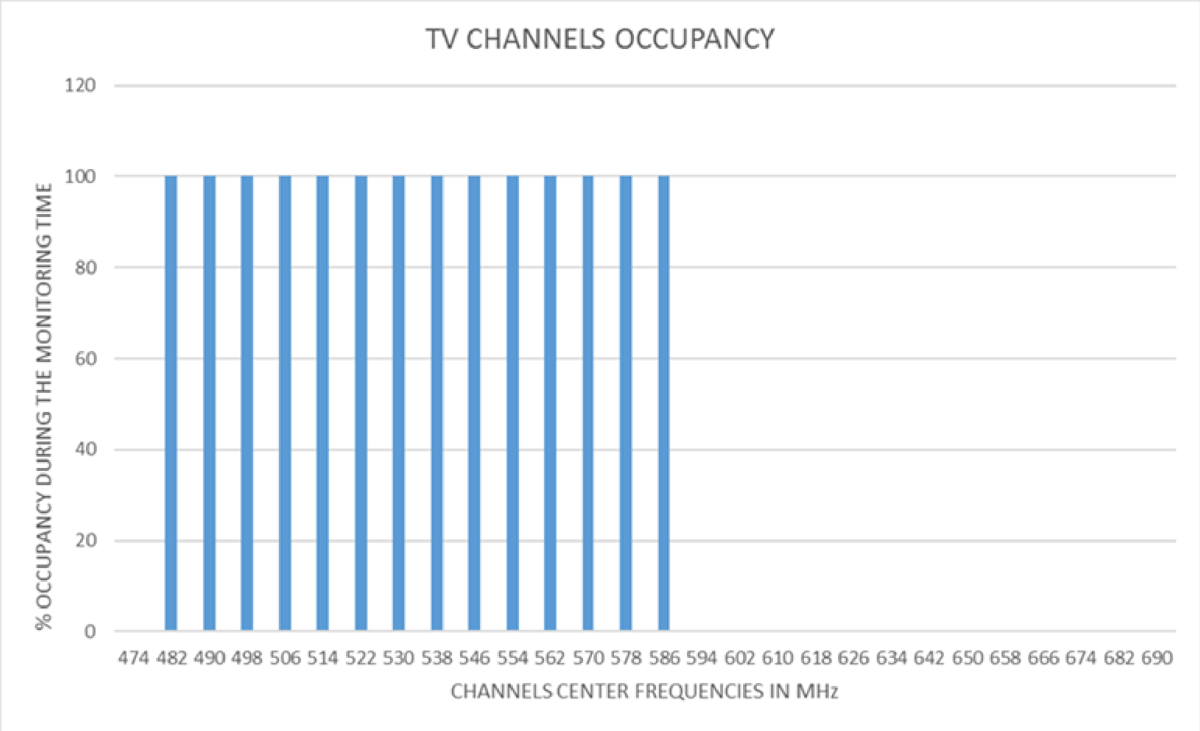

Figure 3: Channels occupancy for the urban area

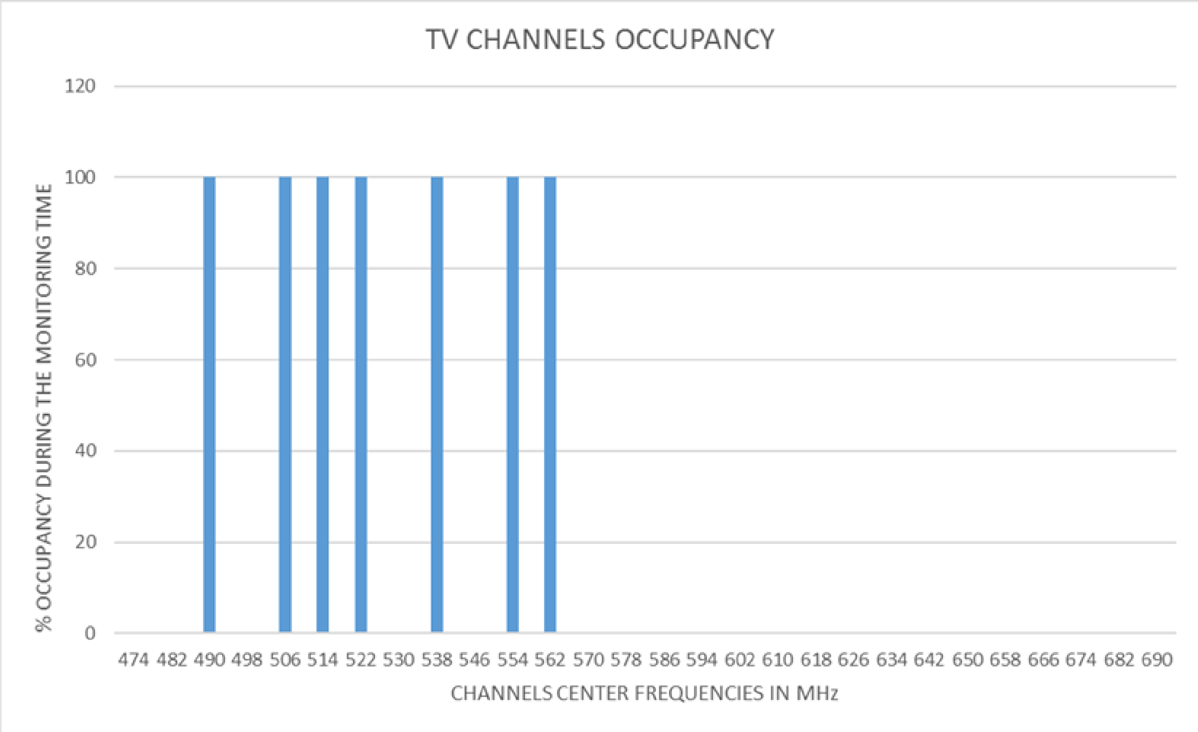

Figure 4: Channels occupancy for the rural area

3.3 Frequency Band Occupancy measurements results

The Table 3 show the number of samples with amplitude above and below the threshold. From the results it could be seen that in urban area the spectrum occupancy of the band is 49.6% while in the rural area it is 26.3%. The Figure 5 and Figure 6 show the plots of signal power against the frequency in the urban and rural areas respectively. It was noted that the results obtained both from the FCO and FBO measurements were very similar.

Table 3: The Frequency Band Occupancy

Area	Total Samples	Samples above Threshold	Samples below Threshold	% of samples above Threshold	% of samples below Threshold
Urban	601	298	303	49.6%	50.4%
Rural	601	158	443	26.3%	73.7%

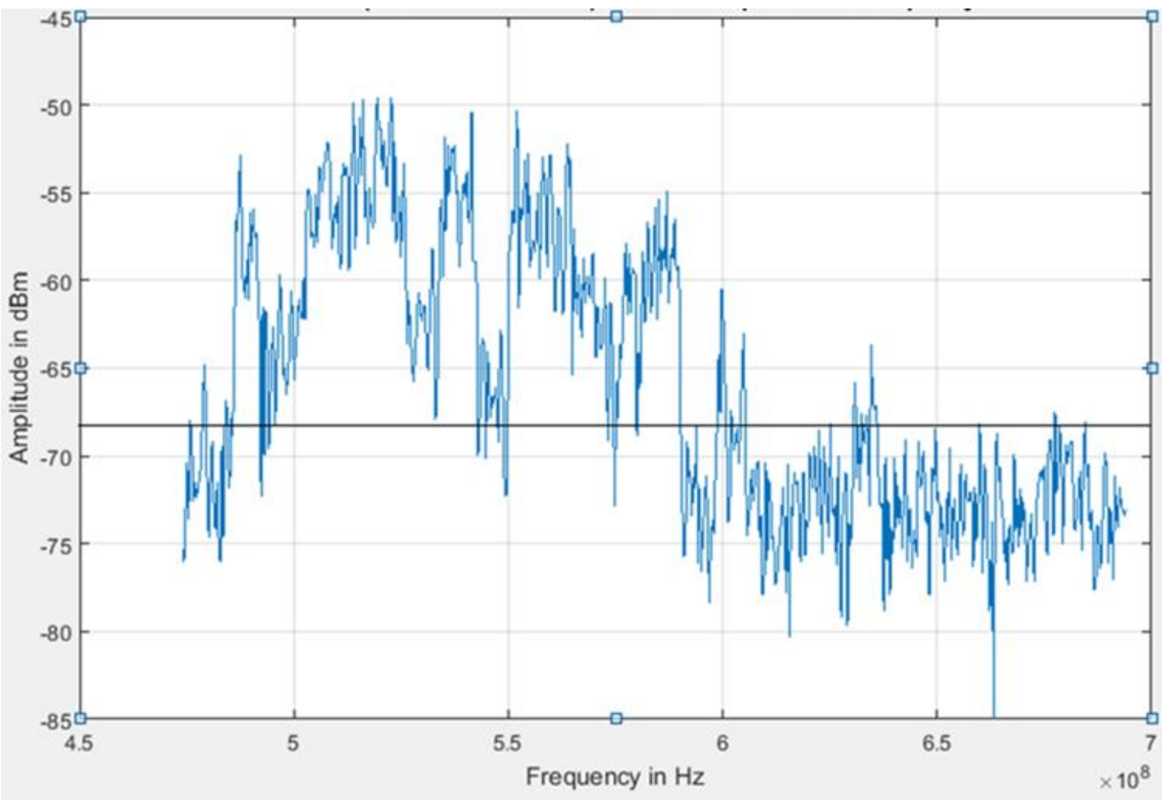

Figure 5: A plot of Signal power against Frequency for the urban area

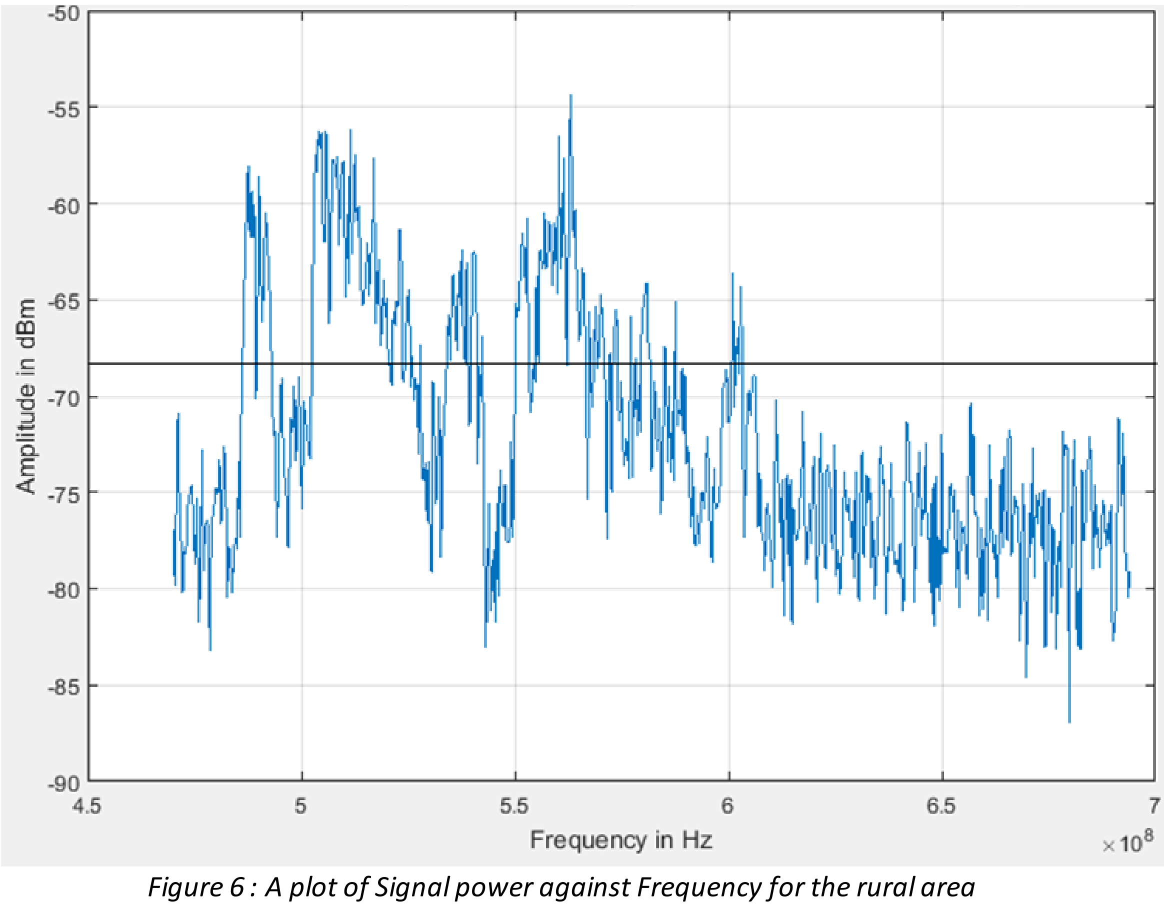

Figure 6 : A plot of Signal power against Frequency for the rural area

4.0 Conclusions

This paper provided an understanding of how to conduct the spectrum occupancy measurements based Report ITU-R SM.2256-1 of 2016 recommendations. If this method is adopted it could enhance direct comparison of results from different measurements.

Results indicated a vast difference in the spectrum resource occupancy between the urban and rural areas in Kenya. In the rural area an occupancy of about 50% was noted and 26% in the rural area. This therefore, confirmed availability of television white spaces both in urban and rural areas that could be utilized for secondary applications like broadband internet, using the cognitive radio enabled devices.

Finally, the results showed that both the FCO and FBO methods of spectrum occupancy measurement over a given frequency band, produced very similar results.

Future research work will include spectrum occupancy measurements in other diffe rent parts of the country and in different bands.

Acknowledgements

The authors would like to acknowledge the AFRICA-ai-JAPAN Project and the Jomo Kenyatta University of Agriculture and Technology for the research funds award.

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