Comparison of Spectrum Occupancy Measurements using Software Defined Radio RTL-SDR with a Conventional Spectrum Analyzer approach.

A. Fanan , N. Riley, M. Mehdawi, M. Ammar & M. Zolfaghari

Abstract **— In the present day Cognitive Radio has become a realistic option for solution of the spectrum scarcity problem in wireless communication. Recently, the TV band has attracted attention due to the considerable potential for exploitation of available TV white space which is not utilized based on time and location. In this paper, we investigate spectrum occupancy of the UHF TV band in the frequency range from 470 to 862MHz by using two different devices, the low cost device RTL-SDR and high cost spectrum analyzer. The spectrum occupancy measurements provide evidence of the utility of using the inexpensive RTL SDR and illustrate its effectiveness for detection of the percentage of spectrum utilization compared with results from the conventional high cost Agilent spectrum analyzer, both systems employing various antennas.**

Keywords **— Cognitive Radio, Software Defined Radio, Spectrum Measurement, White Space.**

I. Introduction

Wireless communications systems are becoming ever more constrained by reduced availability of spectrum, due to the increasing demands of higher data transmission rates and higher channel capacity, whilst the wireless networks are regulated by government policy. Historically, radio spectrum has been assigned to license holders for the long term and over large geographic areas, which has led to spectrum scarcity for potential new spectrum users. Researchers in the UK, US and Europe are engaged in the search for sustainable solutions to this ever-worsening problem. Currently, the Federal communication commission (FCC) in the US has started to allow use of unutilized spectrum in TV band [1] on a secondary-user basis. One of the main motivations for focusing on spectrum availability in the current worldwide digital TV broadcasting band, is that recent studies have shown the existence of significant amounts of vacant spectrum (white space) [2], [3]. Software defined radio is one of the main enablers of the concept of cognitive radio (CR), utilizing a radio architecture with high flexibility and re-configurability through use of software as much as possible instead of relying entirely on hardware. The spectrum available can be sensed and the radio system can adapt to the prevailing radio environment by use of cognitive radio. The goal of this paper is to investigate the spectrum occupancy of the UHF TV band using a low cost software defined radio (RTL-SDR, which is in the form of a USB "dongle") and to compare the results with those derived using a Spectrum Analyzer (SA, agilent E4407B) which is considerably more expensive.

This paper is organized as follows; Section II introduces RTL-SDR based on software defined radio. Subsequently, the geographical locations of the measurements and measurement set-up are described in Section III. The format of the measurement data is described in the section IV whilst data processing methodology is described in section V. Finally, analysis of the measured spectrum occupancy results from both measurement systems is discussed and the paper is concluded.

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II. Software Defined Radio (RTL-SDR)

Historically, hardware-based radio devices have limited functionality and the only method available to modify them is physical intervention, which has implications for production costs and flexibility. In today's world, several devices have been developed recently using SDR which have contributed to the growth of research in CR. Such devices include the Realtek-based Software Defined Radio (RTL SDR). This device contains two main chips, Raphael Micro R820T radio tuner and the Realtek RTL2832U which has USB data pump and an 8-bit ADC as shown in the Fig. 1.

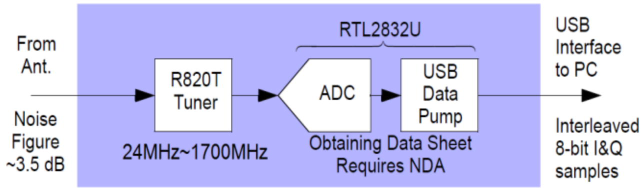

Fig .1. The RTL-SDR high level block diagram.

The main purpose of this design was to receive DVB channels and most versions of the RTL-SDR contain DVB software which can be used to watch TV channels and use TV remote control [4]. Although, the RTL radio have limited sensing bandwidth i.e 3.2 MHz compared to other expansive devices, they can still scan 390 Mhz frequency in less than 2.7s. However, the accuracy of spectrum scan and spectrum measurements using the RTL SDR is affected by various factors as follows: Firstly, RTL SDR dongle sensitivity (or "deafness") which dictates its ability to detect weak signals; another factor affecting the measurements is that the measurement location is not very high up, the dongle may blocked from receiving signals from other transmitter.

Furthermore, most of the RTL SDRs are not constructed as high performance SDRs and the resolution of the USB device has only 8 bits. To achieve a wide dynamic range some SDRs use 12, 14, 16 bits or more. However, the most serious problem seems to be that the RTL SDR is not protected and has a high noise floor which is different from one example to another. The main reasons for this problem might be leakage of RF into the antenna port of the silicon tuner, USB noise, lack of selective front-end filters and local TV/FM/GSM transmitter noise. Also connection of the RTL SDR directly to the PC increases the noise and it is recommend to use a USB extension cable to connect the RTL SDR at least 1 m away from the PC to reduce the noise. As specified in the data sheet, the maximum bandwidth of the RTL SDR is 3.2MHz and depending on the processor speed and memory capacity of the PC, the largest stable bandwidth that can be achieved is 2.4MHz or 2.8MHz; setting the bandwidth too large with a slow PC leads to loss of some samples [5].

III. Geographical location and Measurement Equipment

The measurements were taken at the top of the Applied Science building at the University of Hull, using various types of antennas as shown in Fig.2 which were positioned in direct LOS of all transmitter signals. Most of the channels received in the city of Hull emanate from Belmont and Emley Moor transmitters. The measurement location is roughly 50 Km away from the Belmont transmitter and Emley Moor is approximately 87 km away.

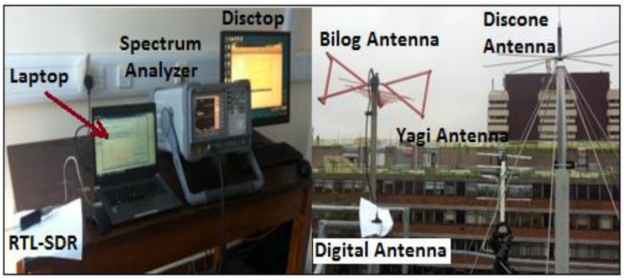

Fig .2.Measurement equipment in this paper: Antennas, spectrum analyser, RTL SDR and laptop

Also, the equipment employed in this study consisted of four separate antennas which were placed on the top of building: digital antenna, TV antenna, Discone Antenna and Bilog antenna, with characteristic which are listed in the Table 1. Each antenna can be fed to either of the two measurement systems: spectrum analyser or low cost software defined radio. The low cost software defined radio (full designation RTL-SDR DVB-T Tuner Receiver) has a frequency range 24MHz~1700MHz. Further information on the specification of the RTL SDR can be obtained from [9]. The validation of correct working of RTL-SDR was done by comparing the result of RTL with that from the spectrum analyzer (Agilent E4407B). The received signals are loaded from the spectrum analyser via a general purpose interface bus (GPIB) connected to a laptop PC where the raw data were stored into Bin files. Data analysis was undertaken offline using Matlab 2014b to produce the occupancy results and then compared with RTL SDR occupancy results based on several criteria.

TABLE 1: ANTENNAS CHARACTERISTIC.

Antenna Name	Frequency Range	Antenna gain	Antenna type
Yagi	470-860 MHz	12 dBi	Directional
Digital	174-30MHz 470-860MHz	3.5 dBi	Omnidirectional
Bilog	30-3000MHz	6 dBi	Directional
Discone	25- 2000MHz	2.2DBi	Omnidirectional

IV. Measurement setup

The main configuration parameters for the RTL SDR and spectrum analyser are shown in the Table 2. The measurement were switched between the two systems to receive the signal from various antennas. Because the RTL-SDR has bandwidth limited to a maximum of 3.2MHz, the work illustrated in this paper, intended to fulfil the need for measurements in the TV band range 470– 862 MHz, has led to development of a measurement methodology and design of a measurement system model for RTL SDR to measure the whole TV bandwidth of 390 MHz. A graphical user interface (GUI) has been designed in Matlab 2014b software as shown in the Fig 3. This system was designed to be more flexible with less complexity to measure a specific channel or any bandwidth within frequency range of the RTL-SDR.

The band is scanned sequentially in segments of 2.4MHz, instead of using 3.2MHz, to avoid lost samples by using a jumping technique. The number of segments used will impact on the overall scan delay. This system was designed to be more flexible with less complexity to measure a specific channel or any bandwidth within frequency range of the RTL SDR. The band is scanned sequentially in segments of 2.4MHz, instead of using 3.2MHz, to avoid lost samples by using a jumping technique. The number of segments used will impact on the overall scan delay.

TABLE 2: RTL-SDR AND SPECTRUM ANALYZER CONFIGURATION

Parameters	Spectrum Analyzer	RTL-SDR
Frequency range	470-862 MHz	470-862 MHz
Resolution Band width	10KHz	851.77Hz
Sweep points	401	512
Sweep time	Auto selected	Auto selected
Gain	off	Tuner gain(0-36)

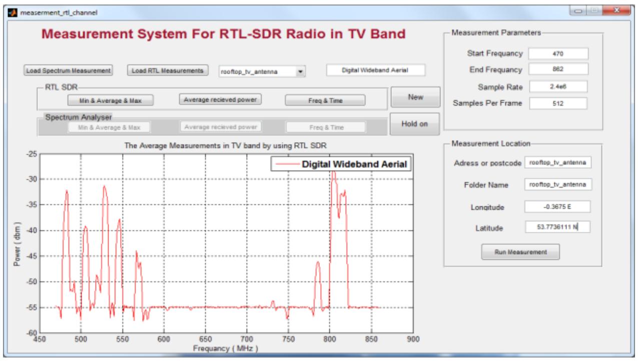

Fig .3. The GUI for the RTL-SDR system

This system was designed to be more flexible with less complexity to measure a specific channel or any bandwidth within frequency range of the RTL SDR. The band is scanned sequentially in segments of 2.4MHz, instead of using 3.2MHz, to avoid lost samples by using a jumping technique as illustrated in Fig. 6. The number of segments used will impact on the overall scan delay.

V. DATA PROCESSING

The steps that have been taken to detect the spectrum occupancy include processing by using the computational package MATLAB 2014b, and may be divided into several areas: Data preparing, Adaptive Threshold setting and Duty Cycle (DC) averaging of TV band spectrum using different antennas.

Data Preparing: The data can be collected as received power from the two devices in the same structure of an [I x J] matrix in mat and bin files.

Adaptive Threshold: The high cost spectrum analysis and inexpensive RTL-SDR have noise floors -97, -55 dBm respectively, that led to selection of different thresholds by selecting fixed margin above the noise floor for each system. The Energy Detection technique is employed to detect the received signal whether below or above the threshold. The decision threshold as recommended by ITU is 10 dB above the average noise floor [6]. On the other hand, some of studies used 3 to 6 dB above the noise floor as mentioned in [7]. We observed that, in the TV frequency range, the external noise floor varies around a common level. Therefore, a threshold 4db above the noise floor was selected for both systems.

Duty Cycle: Measurements that have been collected for the frequency range f_i over a period of time t_j can be represented by pf_i, t_j. The duty cycle can be expressed as a ratio or a percentage of time that a channel is occupied or as a measure of how often a signal is present during a period of time [8]. The duty cycle average is denoted by Df_i, whilst Nf_i denotes the overall number of samples at a frequency channel as shown in equation 1.

$$Df_i = \frac{\sum_{n=1}^{Nf_i} p(f_i, t_j)}{Nf_i} \quad \rightarrow \quad (1)$$

The spectrum occupancy can be calculated for the overall spectrum band or for particular observed frequencies and can be determined by calculating the overall number of samples at time period t_j which is denoted Nt_j. Average duty cycle $D(f_i, t_j)$ can be calculated by using the following equation [3][8]:

$$D(f_i, t_j) = \frac{\sum_{n=1}^{Nf_i} p(f_i, t_j)}{Nf_i \ x \ Nt_j} \quad \rightarrow \quad (2)$$

VI. ANALYSIS OF SPECTRUM OCCUPANCY USING RTL-SDR AND SPECTRUM ANALYZER

Before moving to analysis of spectrum occupancy for each antenna, the first part of the measurement results are shown in Fig. 4 and Fig. 5. Each figure is composed of four different average received power versus frequency plots measured with the four antennas for the frequency range of the measurement study (470-862MHz). Based on the first impression and following the average spectrum allocations, the low portion of the band between 470 to 600 MHz has the nature of the high power broadcast channels in both figures. These channels are considered mostly allocated for broadcast communication and were easily detected by both devices whereas there appears to be less utilization above 730 MHz. Comparing the two figures, the results using the spectrum analyzer indicate that the average received power of broadcast channels by using TV antenna is similar compared with the Bilog antenna in both figures.

However, the digital antenna exhibits weak signals and low utilization in the 600-700 MHz region. On the other hand, use of the digital antenna along with the RTL-SDR indicated heavy utilization in the UHF TV broadcasting band, which is mainly due to the location of the measurement site, which is mostly covered by two broadcast transmitters, Belmont and Emely Moor. In contrast, the Discone antenna is considered the worst antenna among them and has very low utilization and very weak signals. Although the overall measured data indicate that the spectrum occupancy derived by individual antennas in both receiver devices might exhibit large variations, they do not provide a clear picture of how spectrum is utilized in the low cost and high cost spectrum. Therefore, for a better view of the occupancy pattern, we will consider selected antennas in further detail.

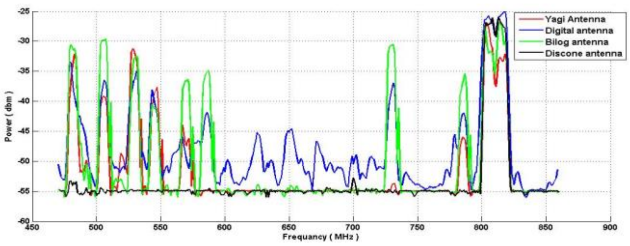

Fig .4. Average received power versus the frequency band 470-862 by using RTL-SDR

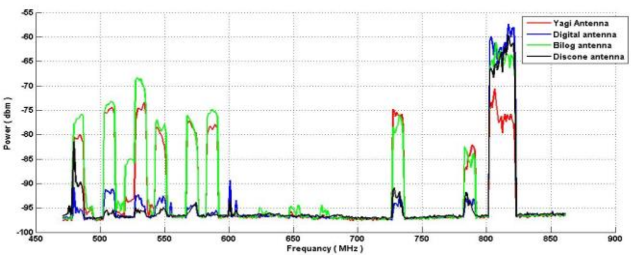

Fig .5. Average received power versus the frequency Band 470-862 by using spectrum analyzer

The measured duty cycle, calculated 4db above the noise floor in both devices, versus frequency, which is indicative of the utilization level of each antenna individually. The average duty cycles for the Bilog antenna when using the RTL-SDR and spectrum analyzer is 25.89% and 26.18% respectively, as illustrated in Table 3.

TABLE 3. THE PERCENTAGE OF DUTY CYCLE AVERAGE IN DIFFERENT ANTENNAS IN RTL-SDR AND SPECTRUM ANALYZER

Antenna Name	RTL-SDR Average DC	SA Average DC	difference
Yagi	20.76%	24.43%	3.67%
Digital	60.25%	11.47%	48.78%
Bilog	25.89%	26.18%	0.29%
Discone	5.64%	9.47%	3.83%

These results indicated that the percentage of the spectrum occupancy is similar for the two systems. The difference between the RTL-SDR and Spectrum analyzer systems when using the Digital Wideband antenna is 3.67%, which is not much different from the value of the difference between devices when using the Discone antenna (3.83%). On the other hand, the percentage of Duty cycle average when was using the Digital antenna is very high in the RTL-SDR case and lower using the spectrum analyzer. Measurements were conducted to investigate the impact of the tuner gain value on the receiver power. Here the CH53 has been selected which is situated within the bandwidth 720-740MHz. The effect of changing the tuner gain value from 0-50 dB on received power is shown in Fig 6.

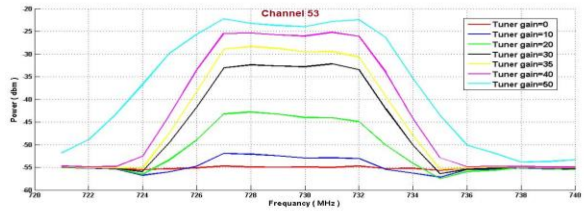

Fig .6. Average received power of channel 53 by different value of tuner gain

VII. CONCLUSION

In conclusion, we have shown that is possible to use the RTL-SDR software defined radio dongle with minimum external hardware as an inexpensive spectrum monitoring device instead of a high cost spectrum analyzer. This opens the door for the development of efficient collaborative cognitive radio systems, where many geographically-dispersed terminals need to sense the radio environment in a cost-effective manner.

REFERENCES

[1] FCC. “Second memorandum opinion and order in the matter of unlicensed operation in the Tv broadcast bands and additional spectrum for unlicensed devices below 900 mhz and in the 3 ghz band,” *Washington, September*, 2010.

[2] E. Pietrosemoli, M. Zennaro, “ TV White Spaces A Pragmatic approach,” In *proceedings of the Sixth International Conference on Information and Communication Technologies and Development*. 2013.

[3] M. R. Dzulkifli, M. R. Kamarud and T. A. Rahman, “Spectrum occupancy at UHF TV band for cognitive radio applications,” In *RF and Microwave Conference (RFM), IEEE International* (pp. 111-114). IEEE. December 2011.

[4] J. Friedt and G. Goavec “E4K and RTL2832U based Software Defined Radio-SDR,” 3 December 2012.

[5] A. Nika, A. Zhang and X.Zhou, “ Towards Commoditized Real-time Spectrum Monitoring, “ University of California,USA,2014.

[6] Handbook Spectrum Monitoring, Radiocommunication Bureau, International Telecommunication Union (ITU), 2011.

[7] R. Chiang, G. Rowe, and K. Sowerby, “A Quantitative Analysis of Spectral Occupancy Measurements for Cognitive Radio,” in *Proc. IEEE Vehicular Technology Conference (VTC)*, Dublin, Ireland, 2007, pp. 3016- 3020.

[8] M. Mehdawi, “Spectrum Occupancy Survey In Hull-UK for Cognitive Radio Applications:Measurement and analysis,” *International Journal of Scientific*, University of Hull,2013.

[9] C. Laufer, ” The Hobbyist's Guide to the RTL-SDR: Really Cheap Software Defined Radio,” Kindle E-book, May 2014.