Spectrum Occupancy Measurements at University Campus in Turkey

İ. Şeflek and E. Yaldız
Department of Electrical & Electronics Engineering, Selçuk University, Konya, Turkey
Email: {iseflek, eyaldiz}@selcuk.edu.tr

Abstract—The recent augmentation of wireless communication applications that need broadband usage increases the importance of Cognitive Radio (CR) which offers dynamic spectrum access. CR aims to provide unlicensed users to access licensed bands (underutilize or idle) without interfering with the licensed users. On the other hand, one of the first steps that should be taken about cognitive radio is the necessity to know the current spectrum usage. For this reason, many spectrum occupancy measurements are performed worldwide, especially in America and Europe. This paper presents spectrum occupancy measurements carried out in Konya, Turkey. The measurements cover 30 to 3000MHz frequency range. Analysis of the data acquired from the measurement is presented in comparison with the national frequency allocation table. The obtained results have shown that many frequency bands are suitable for cognitive radio.

Index Terms—cognitive radio, measurement campaign, spectrum monitoring, spectrum occupancy

I. INTRODUCTION

The rapid emergence of new wireless communication applications which demand broad-bandwidth has shown that radio frequency spectrum is a scarce resource that was considered as infinite. Frequency allocation requirement for the new applications has led to the examination of the current frequency allocation method. The current frequency allocation method is called fixed frequency allocation. Agencies governing frequency allocation assign frequency bands for similar applications in certain time period. They charge high amounts for their services. The result of studies carried out at this allocation method, radio spectrum has been found to be used as idle at high rates depending on frequency, time and space [1].

Insufficiency of fixed frequency allocation method caused the emergence of dynamic spectrum access techniques. The most remarkable and recognized of these techniques is Cognitive Radio (CR). Cognitive radio was proposed in 1999 by Mitola. It is a smart way to know what you want and how to achieve to find the current available bandwidth while ensuring that the user does not experience any disturbance. Cognitive radio identifies the spectrum gaps unused by licensed users and allows unlicensed users (secondary) to access spectrum without any disturbance to primary users [2].

Government agencies in many countries that hold the spectrum management aim to provide dynamic spectrum access, such as cognitive radio, to television bands practice in rural areas [3]. Increasing demand for the use of TV bands required the emergence of a standard by the IEEE. Wireless Regional Area Network (WRAN) 802.22 standard was published in 2011.

Cognitive radio can be implemented in a flawless manner; it can be associated primarily with the full understanding of the current spectrum usage. Therefore, ultra-wideband spectrum occupancy measurements were carried out in many regions worldwide. In particular, in various countries such as America, Germany, New Zealand, Spain, France, England, China and Romania spectrum occupancy measurements were carried out with the current spectrum availability in different scenarios [4]-[11]. These measurements indicate that how frequently one specific frequency band is used and which frequency bands remain unused.

In this context, the measuring system has been established on the roof of Engineering Faculty building in Selçuk University, Konya, to fulfill spectrum occupancy measurements that contain the frequency range from 30 to 3000MHz. This paper presents analysis results of spectrum occupancy measurements.

The remainder of this paper is organized as follows. Firstly, Section II describes measurement setup and methodology. The obtained data from measurements are analyzed and are given in Section III. Finally, the conclusion is submitted in Section IV.

II. MEASUREMENT SETUP AND METHODOLOGY

The measurements were performed outdoors during 15 days from 16 November 2015 to 30 November 2015 at a single location which is Selçuk University, Faculty of Engineering building in Konya (latitude: 38° 01’38” north, longitude: 32° 30’ 38” east altitude:1140 meters). This is a perfect location for the measurement because of direct line-of sight several transmitters. AOR DA3200 broadband discone antenna which has covered from 25MHz to 3000MHz was used during the measurements. Antenna has vertically polarized with omni-directional receiving pattern in the horizontal plane. To improve the measurement sensitivity and make comparisons; pre-amplifier is used in some measurement occasions. The

Manuscript received February 11, 2016; revised June 1, 2016.
antenna or pre-amplifier (if used) was connected by a low loss cable to Rigol DSA 1030 spectrum analyzer. Spectrum analyzer was combined with a laptop via a USB cable. Measurement controls, data acquisition and analysis was realized with MATLAB program. The entire measurement system used in this measurement campaign is shown in Fig. 1.

During the measurement campaign, the whole spectrum band (30-3000MHz) has been divided into thirty bands each having a frequency span of 100MHz. Each 100MHz frequency band has 502 frequency points. The separation between two consecutive frequency points is 199.6kHz. If the frequency bin is larger than the bandwidth of the signal being measured, spectrum occupancy is notably overestimated. On the other hand, occupancy estimation is reasonably accurate as long as the frequency bin size remains acceptably narrower than the signal bandwidth [12]. Spectrum analyzer configuration in accordance with the above is presented in Table I.

Several spectrum sensing methods to detect the presence of a licensed user in a frequency band are available in the literature. Matched filtering, cyclostationary detection and energy detection are some of the detection methods in use [13]. If the power measurement is performed only for the spectrum usage, it is the only detection method that can use energy detection method. Because other detection methods require that the specific characteristics about the transmitter (synchronizing the transmitter, signal parameters, etc...) is known. For these reasons, the energy detection method is used in this study and other similar studies.

The energy of the signal received at the energy detection method is compared with a threshold that is predefined for a specific frequency band. If the signal’s value is above the threshold, the frequency band is considered to be occupied. Otherwise, it is specified as empty. Process of determining the threshold value is extremely important in obtaining the occupancy statistics. When high threshold is set, status of the available spectrum is revealed as incomplete and licensed signals are perceived as noise. On the other hand, when the low threshold value is selected, noise signals are considered as licensed and the spectrum may cause unrealistic situation that have high occupancy rates [7].

To determine the threshold value, the measurement system’s noise figure must be known. Therefore, antenna which is connected to the spectrum analyzer is removed and matched load (50Ω) is connected. After this operation, the noise values are determined for each frequency band. Probability False Alarm rate (PFA) 1% and m-dB methods to determine the threshold values are used. In the m-dB method, threshold is determined by adding m decibel the average noise level.

\[ T(f) = N_{ave}(f) + m \]  

In the PFA 1 % method, the empirical distribution of the noise samples are computed and the set the threshold so that no more than 1% of the measured noise samples are above that threshold.

\[ T(f) = F_{X(f)}^{-1}\left(1-P_a\right) \]  

where \( F_{X(f)}^{-1}\) represents the inverse of \( F_{X(f)}\), the cumulative distribution function of the noise values \( X(f) \) [11]. This method offers a more sensitive determination of threshold value. PFA 1 % method has been used this measurement campaign.

### III. MEASUREMENT ANALYSIS AND RESULTS

The data which is obtained from November 16 to November 30, 2015 are compared with the threshold values that are set for each frequency band. Thus, spectrum occupancy rate is achieved by calculating the average duty cycle value. Average duty cycle is defined as follow.

\[ ADC = \frac{N_f}{T_N} \]  

where \( N_f \) is total frequency amount which exceeds the threshold value, \( N \) indicates the total value of the
measured frequency point in studies, \( T_i \) is time instances during measurement for each frequency point. After the process of analysis, the results are presented as being composed of three graphs for each frequency band. These graphs show a) average power spectral density (upper), b) the instantaneous spectrum is whether full or empty (middle) and c) how often the threshold has been exceeded at each frequency (lower) for 15 days 24 hours a day.

Following the above process, Fig. 2 exhibits 30-174 MHz frequency band results. This frequency band comprises such as radio astronomy, FM radio, radiolocation, Private Mobile Radio (PMR), Aeronautical mobile, meteorological aids, amateur, maritime mobile. This band for 15 day period showed 12.54% occupancy. Especially FM radio and PMR applications are heavily occupied. Fig. 3 indicates 174-230MHz wireless implementation results. Analogue and digital TV broadcast at this frequency range. The occupancy rate is 16.10%.

Fig. 4 shows 230-470MHz frequency band outcomes. It includes applications such as meteorological-satellite, PMR, radiolocation, maritime radar, Industrial, Scientific and Medical (ISM) radio bands, amateur, meteorology, military (especially air force), Instrument Landing System (ILS), Public Protection and Disaster Relief (PPDR). In performed measurements, especially military and PMR frequency bands are intensively used. However, as other applications almost never used, occupancy rate is low and about 4.63%.

Fig. 5 demonstrates 470-790MHz which is known as TV band. In particular, importance of this band increases
because of introduction of standard use of these frequencies for rural areas in the context of cognitive radio by IEEE. Distance to the TV transmitter of measurement site is approximately 25km. Therefore, occupancy rate for TV band is 8.49%. Fig. 6 indicate 790-890 MHz portion. It has 3.34% occupancy rate. Mobile/Fixed Communications Networks (MFCN), tactical radio relay, Radio-Frequency Identification (RFID), PMR effectuate this band. RFID applications which are situated in the measurement region have been observed extensively.

Fig. 7 illustrates 890-960 MHz frequency range. GSM 900 uplink-downlink, GSM Railway (GSM-R) band and an undefined application band are enclosed. GSM-R band intensely is occupied, because of its proximity to the measurement point of the railway line. Additionally, GSM 900 uplink and downlink frequencies occupancy show 41.12%, 91.34% respectively. Occupancy for Fig. 7 is 42.59%. There are many applications for the 960-1700 MHz band. However, any occupancy could not be detected (1.08%), except Distance Measuring Equipment (DME) and Secondary Surveillance Radar (SSR).

Digital Cellular System (DCS)-1800 and Digital Enhanced Cordless Telecommunications (DECT) applications exist at 1710-1900MHz band. Fig. 8 exhibits behavior of the frequency bands. As seen in Fig. 8, DCS-1800 downlink band is under intense occupation. However, only the use of the bandwidth of a DCS-1800 operator causes to lower occupancy (11.07%) of the spectrum.

Fig. 9 demonstrates 1900-2300MHz frequency range. UMTS bands are densely occupied. Occupation rate for UMTS downlink bands (2110-2170 MHz) are 88.37%.
The total occupancy rate for this band gap is 13.24%. Next band includes some applications such as ISM and RFID. Fig. 10 shows behavior of this band. It comprises 2300-2500MHz and occupies 2.87%. Range of 2500-3000MHz band for almost no activity could be detected. Fig. 11 summarizes the whole band. Total occupancy rate for the full studied band (30-3000MHz) is 7.63%. These results indicate that a very large part of the spectrum is found to be idle. Thus the spectrum is very suitable for the implementation of the cognitive radio.

Figure 8. The spectrum situation 1710-1900MHz band.

Figure 9. The spectrum situation at 1900-2300MHz band.

Figure 10. The spectrum situation at 2300-2500MHz band.
This paper presents spectrum occupancy measurements for 15 days 24 hours a day in Selçuk University campus, Konya. This study comprises 30-3000MHz frequency range. The obtained values are analyzed with MATLAB software. Various frequency ranges (230-470 and 790-890) have been identified as suitable for the use of cognitive radio. Also, frequency bands above 1GHz are almost idle. Except for DCS-1800, UMTS and ISM bands for mobile phone frequencies, very low occupancy rate is obtained because of the specifications of measurement setup and use of low power devices.

In the future study, the measurement setup will be established in rural and suburb areas. The obtained results will be compared for three different areas. Suitable frequency bands for cognitive radio in Konya will be determined.

REFERENCES


I. Seflek was born in Konya, Turkey in 1988. He graduated from Electrical and Electronics Engineering in Erciyes University in 2012. He continues M.Sc. in Electrical and Electronics Engineering from Selçuk University. He has been a research assistant since 2013. He is interested in spectrum management, cognitive radio, 5G communication.

E. Yaldız was born in Aksaray, Turkey in 1969. He received B.Sc., MEng and Ph.D. degrees in Electrical and Electronics Engineering from Selçuk University, Turkey in 1991, 1995 and 2002, respectively. He was a teaching assistant from 1992 to 2003, and Assistant Professor from 2003 to 2013 in the Department of Electrical and Electronics Engineering at Selçuk University. He is already Associate Professor in Selçuk University. His current research areas are electromagnetic fields and waves, microwave.