

## EVALUATION OF SPECTRUM OCCUPANCY AND COMPARISON FOR THREE DIFFERENT REGIONS

I. Seflek\*, E. Yaldiz

Konya Technical University, Department of Electrical & Electronics Engineering, Konya,  
42130, Turkey

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### ABSTRACT

Radio spectrum is a scarce source and very significant to measure and monitor. The present spectrum must be exploited efficiently since every new application must be allocated to spectrum. With purpose of using the spectrum efficiently, there are worldwide research efforts on dynamic spectrum access. Among these methods, cognitive radio mostly draws attention. In order to carry out dynamic spectrum access studies successfully, available spectrum must be meticulously analyzed. In this paper, spectrum occupancy measurements between 25-3000 MHz frequency bands were made in three different regions (Selçuklu, Karatay, Meram) of Konya, Turkey in outdoors during six months. Obtained data is presented with graphics. The occupancy ratios are %5.12, %4.46 and %4.19 for Selçuklu, Karatay and Meram, respectively.

**Keywords:** Cognitive Radio; Energy Detection; Radio Spectrum Management; Spectrum Survey; Spectrum Usage.

Author Correspondence, e-mail: [iseflek@selcuk.edu.tr](mailto:iseflek@selcuk.edu.tr)

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### 1. INTRODUCTION

The existence of electromagnetic (EM) waves with the discovery by Maxwell was revealed in 1864. Maxwell's theory was confirmed by H. R. Hertz using an induction coil in 1887 and it



has been experimentally proved by detecting waves. With Marconi's transatlantic experiment took place in 1901, long-distance data transmission via radio waves and EM waves began to take its place among the indispensable part of our lives from that day.

The EM spectrum is defined as the classification of all existing EM radiation in the universe, in terms of wavelength and frequency. EM spectrum is generally called with the application bands such as FM, GSM, radar etc.

Wireless communication applications increase day by day as a result of rapid developments on communication systems in the last 30 years. As the applications increase, efficient use of spectrum has become a necessity. Also, with fixed frequency allocation method used worldwide, a certain portion of the available spectrum for specific applications are allocated in return for high fees at predetermined time intervals. Therefore, spectrum is seen as the most valuable public assets of the country. Although this allocation method provides financially high gain to the states, it causes inefficient use of spectrum. Unproductive use of spectrum caused by the fixed frequency allocation has led to the emergence of new studies for using the spectrum efficiently. Instead of fixed allocation method; studies on systems that can provide dynamic spectrum access opportunities were realized. The most popular of these works is cognitive radio (CR). CR finds available bandwidth by knowing what it wants and how to obtain it in an intelligent way, and it does not give any disturbance to the user while providing it [1]. This definition by International Telecommunication Union (ITU) was evolved as radio system utilizing technology that permits the system to obtain knowledge of its operational and geographical environment, dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge [2]. Additionally, CR is promising dynamic access to spectrum and it also aims to provide unlicensed users with access to the spectrum. This concept suggests that licensed users will also protect themselves from unwanted situations such as interference and noise. While the realization of the concept of cognitive radio studies around the world continuous, the most basic study has been to explore where, how and how long current spectrum is used. That is what spectrum occupancy measurements perform.

A spectrum occupancy study done in the United States, where fixed frequency allocation is

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applied, shows that between 15% and 85% of the allocated spectrum remains idle due to time, frequency and geographical location [3]. For these reasons, the importance of spectrum occupancy measurement is increasing both in the name of efficient use of spectrum and in accelerating the emergence of new technologies. Spectrum occupancy measurements are used to determine which frequency band has low or high usage, how the spectrum is used, equipment parameters of existing users (signal bandwidth, power levels), spectrum occupancy gap width and time statistics, number of transmitters per band and ambient noise. That is, it allows obtaining very important data about the current spectrum. This data is important to demonstrate the spectral usage characteristics of the point being measured [4-13].

In this study, spectrum occupancy measurements were performed in the frequency range of 25- 3000 MHz in three different regions outdoor environments.

The rest of this work is organized as follows. Firstly, Section II presents a summary of worldwide related studies. In Section III, materials and methods used in this study are mentioned. Section IV explains how the measurement operation is performed and what results are obtained at which frequencies at different measurement points. Finally, in Section V; the results obtained in the conducted study are evaluated and compared with previous studies.

## **2. RELATED WORKS**

In this section, the spectrum occupancy measurements that have been done previously are surveyed and presented from different aspects.

The first broadband spectrum occupancy measurement to be mentioned was carried out by Sanders in different cities of the United States (Denver, San Diego, and Los Angeles). The measurements for each measurement point lasted at least two weeks. In the study, HP-8566 Spectrum analyzer and several different antenna structures were used and a unique analysis program was designed. A frequency range of 108 MHz to 19.7 GHz was preferred for measurements. Measurements in the three cities have been determined to be intensively used in the seaside city, and the sea radar is shown as a result [4].

The study performed by Weidling et al. [5] presents common framework architecture for measuring, characterizing, and modeling spectrum usage. In addition, statistical methods and

algorithms have been introduced to provide an understanding that received radiation is a signal or noise in the measurements.

Again in a study conducted in the United States, spectrum occupancy measurements were fulfilled to determine the total amount of spectrum usage in urban Atlanta and rural North Carolina. Measurements covering the 400 MHz to 7200 MHz band range lasted several months. Approximately 5 billion data were obtained and the use of active spectrum was determined. Frequency bands that are unused or underused are determined and contributed to dynamic spectrum access studies [6].

Another measurement for the frequency range of 30 -3000 MHz was performed in Chicago, USA. In the measurement study, a spectrum analyzer, an omni-directional antenna, a log-periodic array antenna, a preselector and a laptop computer were used. The measurement results are presented in terms of maximum power level, instant spectrum occupancy state and duty cycle. Among the measurement results, remarkable results were obtained. The 54-88 MHz TV band showed spectrum occupancy of 70.9%; this rate for the mobile phone band in the 806-904 MHz band is 55%. It has also been found out that many frequency bands (1400-1850 MHz) are not used at all. The occupancy rate for all frequency bands is 17.4%. This proves that most of the spectrum remains idle. In addition, the study is presented in a comparison with measurements previously conducted in New York [7].

Frequency range of 20-6000 MHz was scanned by Wellens et al. [8] in a study in Aachen, Germany. Measurements were made for both indoor and outdoor environments. The measurement system was built with an Agilent E4440A spectrum analyzer, AORDA-5000, AORDA-5000JA and Antennentechnik Bad Blankenburg AG KS 1-10 model antennas and a laptop to cover the frequency range to be measured. The minimum, maximum and average power spectral density are given for all frequency bands for the outdoor environment. In measurements for over a week, at 20-3000 MHz frequency band, almost 100% occupancy was obtained for outdoor environment while this value was 32% for indoor environment. Furthermore, the frequency band of 1000-3000 MHz was quite idle for the indoor environment. It has been tried to determine the appropriate bands for dynamic spectrum access.

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Spectrum occupancy measurements were realized in Auckland, New Zealand in the frequency band between 806-2750 MHz for 12 weeks on weekdays. The aim of the study is to determine the potential opportunities in the spectrum for dynamic spectrum access such as cognitive radio. Measurements were performed both indoors and outdoors. Different noise threshold levels were determined and the effects were compared. It was revealed that the difference between 5-25 dB in the received signals between indoor and outdoor environment. Noise distribution and signal power probability distribution were shown in the graphs. It was determined that GSM 900 downlink band was the most used among the measured frequency bands. In addition, while the calculated occupancy rate was 5.72% for the frequency of 806-2750 MHz indoor; this ratio was 6.21% in the outdoor [9].

As a study carried out in Asia, Singapore spectrum occupancy measurements were performed during 12 week days. The measurements cover the frequency range of 80-5850 MHz. An Agilent E4407B spectrum analyzer and ETS-Lindgren 3149 directional antenna were used. The entire frequency range was divided into 60 MHz bands. Each 60 MHz band was divided into 401 points and the difference between two frequency points was determined as 150 kHz. The 174-230 MHz and 490-614 MHz band (TV) were the two most widely used bands with occupancy rates of 49.05% and 52.35%, respectively. Moreover, since no activity detected in the 2400-2700 MHz band, it was reported that this band was empty. The occupancy rate of the whole measured spectrum was 4.54%. It is also emphasized that Singapore is a small city and may be affected occupancy pattern by wireless communication systems in the cities of neighboring countries [10].

Another study conducted in Barcelona, Spain; the frequency range of 75-3000 MHz was analyzed. Anritsu Spectrum Master MS2721B model spectrum analyzer, AOR DN 753 discone antenna and a laptop were used for measurements performed for two days. The measured frequency range was carried out by dividing into 500 MHz sections. The results are presented with graphs of power spectral density, instant spectrum state and duty cycle. According to the measurement results, frequencies below 1000 MHz are heavily used, but it has been determined that the majority of the regions above 1000 MHz are almost idle. It has been tried to determine the appropriate bands for dynamic spectrum access. The effect of the

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frequency bin (two consecutive frequencies) during measurement is also examined [11].

A study covering the frequency range of 700-3000 MHz for three days in four different regions of Doha in Qatar was conducted. Rohde & Schwarz FSH6 model portable spectrum analyzer, AOR DA5000 model discone antenna and laptop were used. The measurement results are presented with three-dimensional power spectral density graphs. Moreover, they vary according to time and frequency for four different regions. When the results are evaluated, the values show low spectrum usage and appropriate bands are determined for dynamic spectrum access systems [12].

Valenta et al. [13] performed study in the suburbs of the city of Brno in the Czech Republic in the city center and suburbs of Paris in the frequency band 400-3000 MHz. In the study, the measurement parameters for each region were presented and the correlation for spectrum usage was examined in these regions. GSM 900 downlink band was the most widely used band among three regions. For Brno, Paris suburban and city center, the spectrum occupancy rates in the frequency range of 400-3000 MHz were calculated as 6.5%, 10.7%, and 7.7% respectively.

In the study of Benitez and Casdevall [14], a summary of the work carried out up to that time has been presented and it has been suggested that a specific methodology should be established for spectrum occupancy measurements. In the study covering 75-7075 MHz frequency band, the details of what should be done during the measurement are discussed in the context of time and frequency dimension. Important information has been given about how the data will be post-processed after collection.

Another study in Europe was conducted in Bucharest, Romania, at a frequency range of 25-3400 MHz. Anritsu MS2690A signal analyzer, Sirio SD1300N and Aaronia Hyperlog 4060 antennas were used. MATLAB program was preferred for data collection and analysis. In the analysis part, different threshold values are presented by comparing the effect on occupancy statistic. The average occupancy rate for all frequency bands was calculated as 12.19%. It was determined that certain frequency bands were very low utilized and may be suitable for dynamic spectrum access [15].

Wellens and Mahonen provided important information from spectrum occupancy

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measurements. Same measurement setup was established in 2007. Measurements were made in Aachen, Germany and Maastricht, Holland. The power-probability density function statistic is obtained for the measurement points. A modeling study was carried out to calculate the duty cycle. For some frequency bands, comparison of different duty cycle distribution was presented using appropriate thresholds. Modified beta distribution was applied for duty cycle. In addition, the study on adaptive spectrum sensing was carried out [16].

A study by establishing a measurement system covering the frequency range of 30-6000 MHz was fulfilled out in Chicago, USA. The study conducted over three years was quite extensive when compared to others. The occupancy ratios of the 30-3000 MHz band were presented comparatively for the years 2008, 2009 and 2010. These ratios were calculated on average as 18%, 15% and 14% for all bands, respectively. Furthermore, occupancy values measured for fifty-two weeks for certain frequency bands are shown comparatively on a day-by-day and TV white space frequencies, which indicate the suitability of the TV bands determined by the FCC for dynamic spectrum access [17].

For another measurement of the spectrum usage case, the coastal and residential area of Mumbai, India was preferred. The frequency range of 700-2700 MHz was selected for the study. During the two days measurements, the frequency range was divided into eight sub-bands. The GSM 900 and GSM 1800 bands were identified as the most active bands and the occupancy rates were calculated as 37.20% and 31.71% respectively. The average occupancy rate for the entire measurement range was 6.62%. It has been shown that frequency bands are appropriate for the cognitive radio providing dynamic access to the spectrum in studied region [18].

Another spectrum occupancy measurement was carried out in the Ho Chi Minh City and Long An province in Vietnam. The aim of the measurement was to examine the state of the allocated spectrum for different applications and to serve them to new applications by identifying unused or underused frequency bands. The equipment included R&S EM550 VHF/UHF digital broadband receiver and several different antennas. Frequency range of 20-3000 MHz was chosen and it has been stated that some bands was never used in measurements over four months. The power spectral density for all bands was given in Ho

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Chi Minh City study. The most intense occupancy rate for this city is the analog TV band (470-806 MHz) with 58% rate. In addition to comparing the band-to-band occupancy measurements for two different regions, a study in the New York City of America was also used in comparison. The average occupancy rate for the 20-3000 MHz bands was calculated as 11.19% for the Long An region and 13.74% for the Ho Chi Minh City [19].

Spectrum occupancy measurements were fulfilled in the Bristol city of England in the frequency range of 300-4900 MHz for more than 6 months. A specific system was established with a spectrum analyzer, two different antennas, a switch to make the antenna preference, and a computer, was established. It was interpreted that the spectrum activity decreased at the weekend and the hourly spectrum occupancy state was studied for 24 hours. In addition, occupancy rates for all bands were provided for indoor and outdoor usage [20].

Important topics such as the setup of the measurement system, adjustment of the spectrum analyzer for the measurement, the necessary algorithm for its control, method to obtain the data and data format were shared by Benitez and Casdevall. A comparison of the studies carried out in Barcelona and Castelldefells was also presented in this study [21].

Measurements were taken at four different locations around the Guangzhou region in the south of China. The EM 550 digital receiver, the measurement frequency coverage antennas and a laptop were used in the measurements for a week in the frequency range of 20-3000 MHz. In the study, methodology, data storage, and the data analysis were discussed in detail. TV white space frequencies were determined. The measurement results of four different regions were compared and the fitness of the occupancy statistics to the beta distribution was investigated. The study found out that most of the available frequency bands were suitable for cognitive radio [22].

Spectrum occupancy measurements performed in multiple locations in London. Temporary measurement systems were established in many areas, such as a lot of streets, airports and shopping centers where people live extensively, except for the system installed at one fixed point. Measures taken over a week revealed how the spectrum is used for a metropolitan city. Three spectrum analyzers were used in the measurements and the AOR DA753G model was chosen as the antenna. 75-3000 MHz frequency range was scanned and focused on analysis of

GSM bands. Moreover, it was performed correlation studies among the measurement points for dynamic spectrum usage in the context of time, space and frequency domain [23].

Spectrum occupancy measurements for the 470-790 MHz UHF TV band in eleven European countries were performed. In particular, the study aimed to determine the spectrum gaps (TV white space) arising from digital TV broadcasting after the end of terrestrial analog TV broadcasting. By determining the white spaces for the countries according to area and population; it was compared with another study conducted in America [24].

A comparative measurement was implemented by Kliks et al. [25] in Barcelona, Spain and Poznan, Poland. Noise floor was obtained with a pragmatic approach by comparing the inside and ambient noises. The measurement parameters were similar in both cities in order to obtain comparative results. Anritsu MS2721B model spectrum analyzer and AOR DN753 model antenna were used in Barcelona measurements. In Poznan, Rohde & Schwarz FSL6 model spectrum analyzer and AORDA-753G model antenna were used. The measurements in Barcelona lasted about four months, but this time in Poznan was one week. It was determined that most commonly used band for the results obtained for the two cities was the GSM 900. The average occupancy ratios calculated for all frequency band ranges were presented as 22% and 27% for Barcelona and Poznan.

In China's capital Beijing 440-2700 MHz frequency range was scanned. In the measurements realized for two days, valuable data were obtained about the current spectrum. A measurement system was designed with Agilent N9030A spectrum analyzer, the Boger DA-5000 antenna, the uninterrupted power supply for 24 hours of non-stop measurements and a laptop. The frequency bands heavily used 470-806 MHz TV band and 935-960 MHz GSM 900 band. For all measured bands (440-2700 MHz), the active spectrum utilization rate was calculated to be 15.2% [26].

In the seven different cities of Europe, the frequency range of 110-3000 MHz was scanned for two days. Especially, it is focused on the daily activity and duty cycle model of the GSM 900 and GSM 1800 bands. Use of the ISM (industrial, scientific, medical) band was also investigated in two of the locations studied. Rohde & Schwarz FSL6, Tektronix RSA 6100A, Rohde & Schwarz FSQ-26 and Anritsu MS2690A spectrum analyzers were used. AOR DA

3200 and AOR DA 753G were the preferred antennas. For seven cities, the duty cycle-cumulative distribution function tables for GSM 900 and 1800 bands were presented [27].

UHF (470-854 MHz), GSM 900 downlink (935-960 MHz) and GSM 1800 downlink (1805-1880 MHz) frequency bands were measured in Pretoria Hatfield region, South Africa, with a unique measurement system and a software for six weeks. A specific spectrum occupancy method for raw measurement data was determined and analyzed. Occupancy rates for UHF, GSM 900 downlink and GSM 1800 downlink bands were calculated as approximately 20%, 92% and 40%, respectively [28]. Martian expanded his work in Romania and carried out spectrum occupancy measurement in the 25-3400 MHz band in Maneciu village and Bucharest city center. In the study [29] different threshold value methods were compared. Statistical difference of occupancy among them was shown. Weekday and weekend measurements were compared on a time basis and the results were presented for two different regions. While 14.19% occupancy statistics were calculated for all frequency bands in Maneciu village, this value was 21% in Bucharest.

In the study conducted in Grand Forks, North Dakota, USA, the frequency range of 824-5800 MHz was scanned to determine the spectrum usage. The Universal Software Radio Peripheral (USRP) system with high temporal resolution compared to previous studies was used and energy detection and auto correlation were applied. Average occupancy rates for certain bands were presented [30].

Due to the large number of measurement studies, some researchers have encouraged these studies to be brought together. The work carried out by Das [31] covered world-wide studies and spectrum occupancy models. A similar kind of research was also fulfilled by Chen and Oh. Examination of spectrum occupancy measurements on statistical scale and the spectrum prediction models with the obtained results were reported in detail in the study [32].

### **3. MATERIAL AND METHOD**

Spectrum occupancy measurements were initiated on 1st October 2015 by establishing a measurement system on the roof of the Engineering Faculty Building of Selçuk University.

Measurement campaign was ended with Meram region measurements on 14th March 2016. Measurement locations are presented in Table 1 and also shown on the map in Figure 1.

**Table 1.** Measurement locations

Location	Latitude	Longitude	Altitude	Type
Selçuklu	N 38° 01'38"	E 32° 30' 38"	1140 m	Urban
Karatay	N 37° 51'09"	E 32° 30' 28"	1020 m	Suburban
Meram	N 37° 45'58"	E 32° 24' 34"	1099 m	Suburban

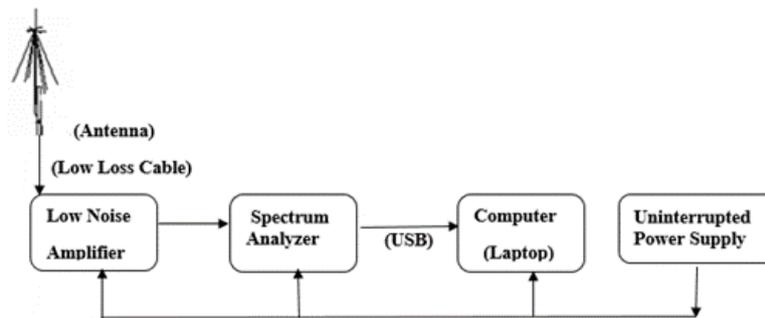


**Fig.1.** Measurement Locations in Konya, Turkey

In order to carry out spectrum occupancy measurements, it is necessary to set up a measurement system by bringing some devices together. Generally the measurement system consists of one or more broadband antennas depending on the frequency range to be operated, a low noise amplifier with regard to the measurement area relative to the transmitter and considering the measurement accuracy, a low loss cable to prevent power loss and a spectrum analyzer. The spectrum analyzer is controlled by a computer and software designed specifically for the application Figure 2 shows the block diagram of the measurement system used.

The measurement system was established in three different regions of Konya. Rigol DSA 1030 Spectrum Analyzer which covers 9 kHz-3GHz frequency range also has 100 Hz sensitivity and -138 dBm noise level was used. AOR DA 3200 antenna was determined to be suitable for measurements. It has vertically polarized with omni-directional receiving pattern in the horizontal plane. It covers 25-3000 MHz frequency range. AOR LNA 4000 low noise

amplifier and a laptop were other equipment utilized for the measurement system. Data acquisition and spectrum analyzer control was performed with a software program.



**Fig.2.** Measurement System

The measurement settings of the spectrum analyzer were made taking into account the lowest bandwidth of the existing signals. The frequency range (25-3000 MHz) for lasting the six-month measurement campaign in three regions is divided into 30 subbands of 100 MHz each. To provide the lowest signal bandwidth, it is divided into 502 frequency points in every 100 MHz subband. Thus, two adjacent frequency points measured successively is obtained at 199.6 kHz. The aim of this arrangement is that the frequency bin value must not be larger than the signal bandwidth. Otherwise, the spectrum occupancy would be outstandingly overestimated. In order to obtain the correct occupancy statistics, frequency bin should be lower than the signal bandwidth [14]. The spectrum analyzer settings used during measurements are shown in Table 2.

**Table 2.** Spectrum analyzer settings

Parameter	Value
Frequency Span	100 MHz
Resolution Bandwidth (RBW)	10 kHz
Video Bandwidth (VBW)	10 kHz
Reference Level	-10 dBm
Scale	10 dB/div
Detection Type	RMS detector
Sweep Time	Automatically

A software has been prepared to record the raw data from the spectrum analyzer. The data are recorded in the form of a matrix. Data's time, frequency and power information are in the matrix form, is shown in Table 3.

**Table 3.** Recorded power in matrix form

	$P(t_1, f_1)$	$P(t_1, f_2)$	...	$P(t_1, f_j)$
$M=$	$P(t_2, f_1)$	$P(t_2, f_2)$		$P(t_2, f_j)$
	...	...	...	...
	$P(t_i, f_1)$	$P(t_i, f_2)$	...	$P(t_i, f_j)$

M represents  $y(n)$  where  $y(n)$  shows a matrix for received power at each n point and  $P(t_i, f_j)$  shows the recorded (received) signal power in the matrix,  $f_j$  and  $t_i$  denote frequency and time slot respectively. After the raw data is obtained, utilizing spectrum sensing techniques, it is determined that the channel status is idle or occupied, and average occupancy rates for each frequency band are calculated.

Spectrum sensing is an important matter in spectrum occupancy measurements. Using spectrum detection methods, the presence of licensed users in the current spectrum can be determined. Several methods are available in the literature to determine the presence of signals and users in the spectrum. Among these methods, energy detection and eigenvalue based detection do not require prior knowledge of the received signal. Spectrum is evaluated with power samples of received signal. But specific characteristics (signal parameters, synchronizing the transmitter, etc...) of the emitted signal need to be known in other methods such as matched filter detection, cyclostationary feature detection, waveform-based sensing and radio identification-based sensing [33]. Because of simple calculation, less application complexity and receiving only the power samples, the energy detection method has been used in similar works and in this measurement studies.

Signal's presence in energy detection method is obtained by comparing the energy of the received signal with the threshold value belonging to the noise floor. The disadvantages of this detection method are the inability to distinguish the spread spectrum signals and depends on noise values. The most important problem for this method is to determine the threshold accurately [34]. In the measurement campaign, the received signal from the environment can be expressed as follows

$$y(n) = s(n) + w(n) \quad (1)$$

where  $s(n)$  is the signal and  $w(n)$  is the additive white Gaussian noise and n represents the sample index. Detector's energy output is expressed the obtained power values matrix M as

follows.

$$M = \sum_{n=1}^N |y(n)|^2 \quad (2)$$

where N indicates the number of signal samples. The state of the signal is determined by comparing the M values with the threshold values determined for each frequency band.

$$S = \begin{cases} \text{If } M < \lambda, H_0 \\ \text{If } M > \lambda, H_1 \end{cases} \quad (3)$$

S implies channel situation and  $\lambda$  indicates threshold value for frequency bands.  $H_0$  and  $H_1$  hypotheses are represented as follows.

$$H_0 : M(n) = w(n) \quad (4)$$

$$H_1 : M(n) = s(n) + w(n)$$

$n=1, 2, 3, \dots, N$ , where N is total received sample number during measurement campaign. If  $H_0$  state is calculated channel is idle, otherwise  $H_1$  is validated and channel is expressed as occupy.

Threshold value determination is crucial for processing raw data and obtaining occupancy statistics. When a high threshold value is specified, the state of the existing spectrum is revealed incompletely (underestimation) and licensed signals can be perceived as noise. On the other hand, when the threshold value is arranged low, the noise signals may be perceived as licensed signals, which may cause the spectrum to have an unrealistic high occupancy rate (overestimation).

Determining the noise figure of the measurement system is a practically applied method for threshold value at each frequency band. The antenna connected to the spectrum analyzer is removed and replaced with (50  $\Omega$ ) matched load and the noise is measured. Using the obtained noise values, the threshold value is determined. The maximum noise criterion, the m-dB criterion and the PFA 1% criterion are used in the threshold value determination. In the spectrum occupancy measurements, the parameter indicating the spectrum occupancy is expressed average duty cycle. For all location average duty cycle is calculated similarly [14]. Also, PFA 1 % criterion has been used during this measurement campaign.

#### 4. MEASUREMENT RESULTS AND DISCUSSION

The measurement results for each location in the six month measurement campaign at entire frequency range (25-3000 MHz) are presented. This frequency range is separated specific bands and the results is compared for three locations. For the evaluation of the measurements, the types of applications in the available spectrum were obtained from the national frequency spectrum chart. In addition, spectral occupancy results are presented in order of Selçuklu (Location 1), Karatay (Location 2) and Meram (Location 3) [35].

Firstly, 25-174 MHz band is analyzed and the results are obtained. There are many applications in this frequency range. Some of them are defense systems, citizens band (CB) radio, industrial scientific medical band (ISM), instrument landing system (ILS) and VHF omni directional radio range (VOR), FM radio, air to ground communications (military), private mobile radio/ public access mobile radio (PMR/PAMR). In particular, the frequency bands where FM radio and special access radio applications are allocated have been continuously occupied throughout the measurement period for three locations. Some days especially for Selçuklu location ILS and air to ground communication bands are determined as occupied because of nearness to airport and military zone. In other locations, the occupancy rates for these bands are slightly less. The average occupancy rates calculated for the three locations in the 149 MHz frequency range are 14.87%, 20.30% and 19.75%, respectively.

174-230 MHz is allocated for Terrestrial VHF-TV broadcasting and Terrestrial Digital audio broadcasting (T-DAB) in Turkey. Since digital audio broadcasting has not been introduced yet in Turkey, no transmissions have been detected in the range of 216-230 MHz. Therefore, VHF TV broadcast causes the frequency range to be occupied. The average occupancy rate for this frequency band (174-230 MHz) is 5.01% for Selçuklu. For Karatay and Meram these values are 12.16% and 5.97% respectively. The occupancy rate of Karatay measurement point is higher than other points due to the fact that location is close to the transmitters. It is estimated that this band will show a higher occupancy rate by switching to digital broadcasting.

The most idle frequency range below 1 GHz of spectrum is 230-470 MHz in three regions. Applications assigned to frequency range are Air to Ground communications (military),

tactical radio relay, PMR/PAMR, maritime radar, PPDR (Public Protection and Disaster Relief) and meteorology. The average duty cycle for locations 1, 2 and 3 are 1.09%, 0.43% and 0.53%.

UHF TV band is very important for cognitive radio. Digital TV broadcasting, which demands 6-8 folds fewer spectrum than terrestrial analog TV broadcasting, has begun to be used in many countries. In these countries, it is planned to use the spectrum emanating from terrestrial TV broadcasts for cognitive radio applications. Even in rural areas where the analogue TV band is not used, the WRAN (wireless regional area network) standard was determined by the IEEE. The 470-790 MHz band of the spectrum is allocated for terrestrial UHF-TV. The occupancy rate for this frequency range is 4.95%, 9.93% and 5.06% for each location, respectively.

Applications such as tactical radio relay, Long-Term Evolution (LTE) -Advanced, radio frequency identification (RFID) and mobile / fixed communications network constitute 790-890 MHz part of the spectrum. Activity is determined at the frequencies allocated for RFID. In addition, the frequency band 791-887 MHz has been allocated to LTE-Advanced by tendering to different mobile operators. The availability of test transmission at the 790-820 MHz LTE-Advanced downlink frequency range has been determined at Meram measurement point, as the date of the LTE-Advanced transition in Turkey is on April 1, 2016 and the measurement dates are very close to this trend. However, Selçuklu and Karatay measurements were carried out before this date. So no transmissions could be detected on these frequencies. Average occupancy rate are 1.54%, 0% and 25.04% for Selçuklu, Karatay and Meram, respectively.

In addition to the GSM-R, GSM 900 band's uplink and downlink bands; 890-960 MHz frequency band which started to include the IMT-Advanced downlink frequency together with the tender was determined to be the most frequently used band. 890-915 MHz is the uplink band of GSM 900 and three operators have the right to use it in this frequency band. The occupancy rate for the uplink frequencies is approximately 1% in the three regions. Low power consumption of the devices (mobile phone) and the multiple access technique used by the GSM 900 make it difficult to get the real value of spectrum usage in this band. The

frequency range of 921-925 MHz is allocated for the application of GSM-R (GSM Railway) and it is determined that the transmission is available at three measurement points depending on the high-speed train transport system. In addition, 925-935 MHz frequency band has been allocated for marine radar. The absence of marine in Konya has questioned the transmission in this region. As a result of the research, it has been determined that this 10 MHz frequency band has been assigned to an operator under LTE-Advanced. It is understood that test transmission of the LTE-Advanced application have been started for an operator during the measurement campaign. 935-960 MHz frequency band is allocated as the GSM 900 downlink band and it is the most active band during six months period. Selçuklu, Karatay and Meram measurement points for the GSM 900 downlink band occupancy rates are 95.34%, 69.83 and 83.13%, respectively. By the same measurement points sequence, these rates for entire 70 MHz band range are 40.39%, 31.60% and 42.14%.

960-1700 MHz band range has been allocated for applications such as secondary surveillance radar (SSR), aeronautical surveillance, radio astronomy, T-DAB, INMARSAT, meteorology and weather satellites. During the measurement campaign in Selçuklu, signal is detected at 1175 MHz. It is estimated that this is the secondary surveillance radar. The fact that the measuring point is close to the airport makes it easy to detect. No signal is detected at the other two measuring points. 740 MHz is almost never used. Average occupancy rate is 0.04%. At other points, this wide frequency range is idle.

Weather satellites, fixed link, GSM 1800 uplink, tactical radio relay, GSM 1800 downlink and digital enhanced cordless communications (DECT) applications are in the 1700-1900 MHz frequency range. In GSM 1800 technology used by a single operator, it is assigned as 1710-1785 MHz uplink frequency. In the three regions, very low spectrum occupancy rate is obtained, which is similar to that of the GSM 900 band. 1805-1880 MHz is arranged as downlink frequency for GSM 1800. The calculated occupancy rates at all locations for the GSM 1800 downlink band are 18.78%, 15.58 and 13.43% respectively. Furthermore, activity has been revealed in the 1880-1900 MHz frequency range allocated for the DECT application. Occupancy rates obtained in the frequency range 1700-1900 MHz are 7.92%, 5.85% and 5.03% for location 1, 2 and 3.

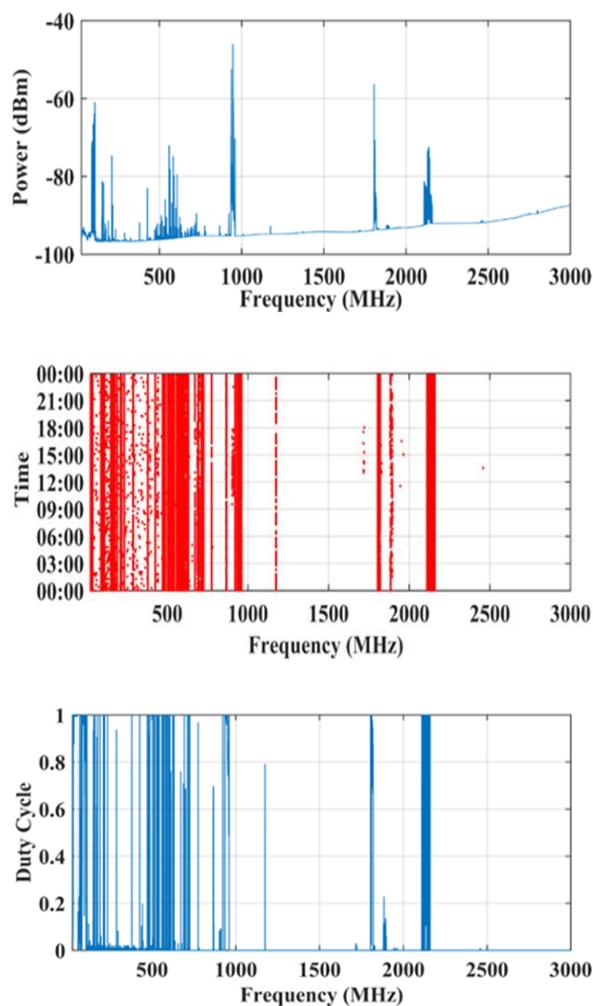
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The frequency band of 1900-2300 MHz, which constitutes the 400 MHz frequency band range, contains many applications. Some of these applications are fixed link, space research, point to multipoint link and 3G. It has been observed that activities are available at 1920-1980 MHz uplink and 2110-2170 MHz downlink frequencies where 3G bands are present. Especially, the allocated downlink frequency range for base stations is occupied during campaign. However, the band's occupancy rate is low because the measuring point (suburban) in Meram is probably far from the transmitters of some operators. Average spectrum occupancy rates obtained in the 3G downlink band for Selçuklu, Karatay and Meram are 78.03%, 48.74% and 16.70% respectively. For the 400 MHz frequency band, these ratios were 11.69%, 7.28%, and 2.5%.

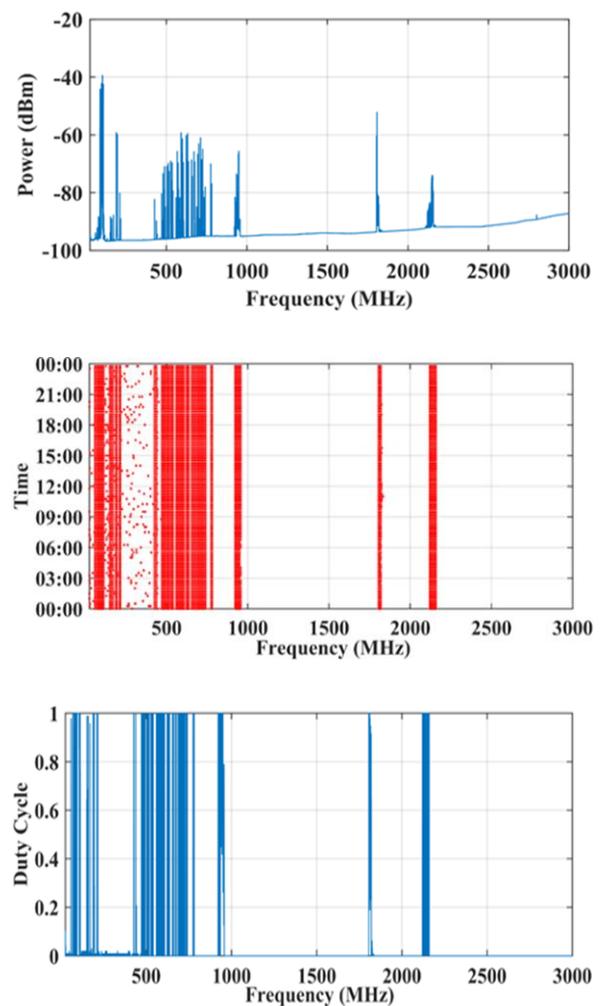
Applications such as RFID, wideband data transmission systems, fixed links and aeronautical telemetry have been allocated for the frequency range of 2300-2500 MHz. This frequency range includes the industrial, scientific and medical (ISM) band (2400-2483.5 MHz), which is widely used worldwide. Although no activity intensity is observed, activity is detected in some parts of the ISM band in the Selçuklu measurement point. Especially the region where the measurement is made is university and the presence of wireless internet service in this frequency range explains this activity. No transmission is detected in the other two regions. However, it is difficult to detect ISM band signals because the devices are located in the building and they are broadcasting at low power and the measurement system is installed outside. 200 MHz frequency range is almost idle, except for the Selçuklu measurement point. In this point, average occupancy rate is 0.04%.

Finally, the average occupancy rates for 2500-3000 MHz range of the spectrum are calculated in three regions. This frequency range has been allocated to applications such as radio astronomy, space research, aeronautical navigation and radiolocation (military). However, following the LTE-Advanced tender, three different operators are leased for use in this application with a frequency range of 2500-2670MHz. Although there is no transmission during measurement campaign; at 2800 MHz, signal powers are detected but remain below the threshold. This frequency is allocated to radiolocation (military) in national frequency spectrum chart. Average occupancy rates for all regions are 0%.

Calculated results from the measured raw data during measurement campaign (six months) for each region is presented average power spectral density, instantaneous spectrum state and average duty cycle for whole frequency range (25-3000 MHz). In Selçuklu, Karatay and Meram for whole spectrum band results are %5.12, %4.46 and %4.19, respectively. Figure 3 shows Selçuklu measurements results. Karatay measurement results are demonstrated in Figure 4. The measurement results for the Meram, the last measurement region, are indicated in Figure 5. The graph comparing the results of the band-band three regions is presented in Figure 6.



**Fig.3.** Spectrum occupancy measurement results for Selçuklu



**Fig.4.** Spectrum occupancy measurement results for Karatay

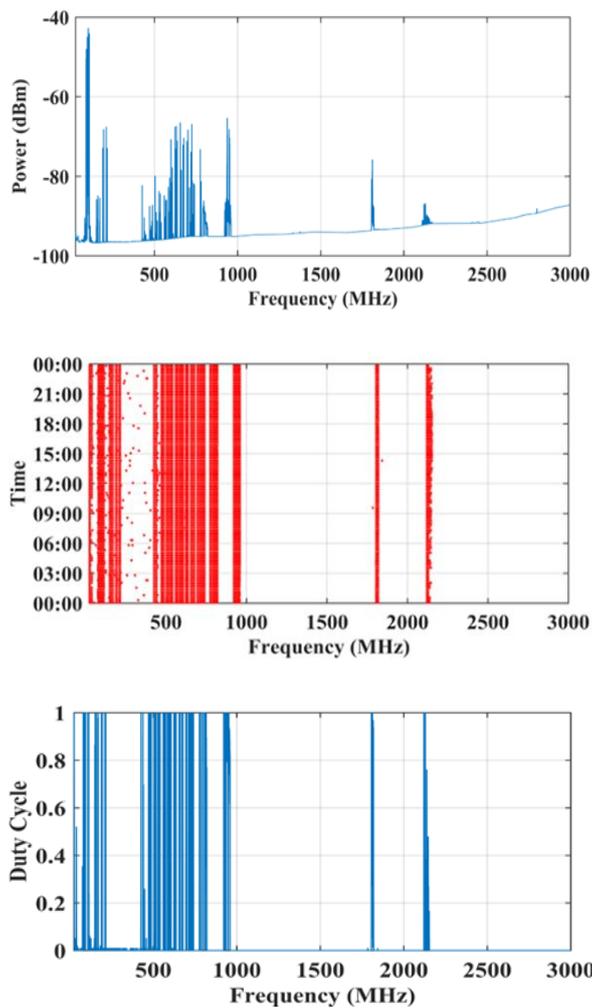


Fig.5. Spectrum occupancy measurement results for Meram

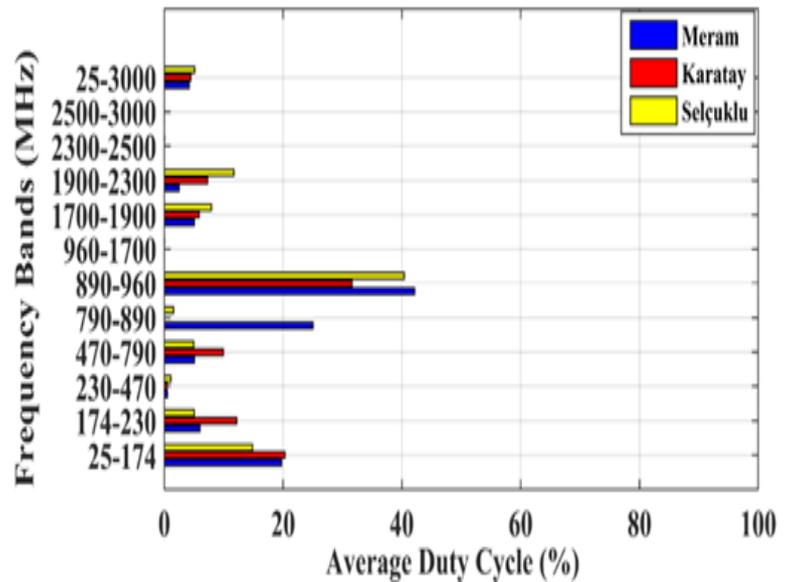


Fig. 6. Comparison of Band-Band Results of Three Regions

### 5. CONCLUSIONS

In this study, spectrum occupancy measurements are performed in the frequency band between 25-3000 MHz at three different measurement regions in Konya. Measurement campaign is spread over a period of six months.

Especially when the results obtained for the three regions are examined, it is determined that the usage of the part of the spectrum below 1 GHz is excessive. Above 1GHz, no transmission exists except for certain bands. In particular, the frequency ranges 230-470 MHz, 960-1700 MHz and 2500-3000 MHz have been frequency bands in which almost no activity can be obtained within the three measurement points.

It has been observed that the downlink bands of GSM communication applications are heavily

used and they occupy the spectrum for 24 hours. It has been difficult to detect the activities of the uplink frequencies owing to the measurement setup, the low power of the devices and the used technology, GSM band and other communication applications depending on the spread spectrum technique. Starting of LTE-Advanced in Konya is observed during the measurement campaign.

Average occupancy rates of GSM900, GSM1800 and 3G downlink bands for Selçuklu are 95.34%, 18.78% and 78.03, respectively. The results obtained for Karatay are 69.83%, 15.58%, and 48.74%. Although Meram is located in a section where the garden and the vineyards are located in terms of the measurement point, spectrum usage is high in these bands. For this location, the occupancy rates of GSM 900, GSM1800 and 3G downlink bands are calculated 83.13%, 13.43% and 16.70% respectively. The average occupancy rates for Selçuklu, Karatay and Meram measurement locations in the 25-3000 MHz frequency band are 5.12%, 4.46% and 4.19%, respectively. The results of studies carried out in different countries and comparison with measurement campaign are presented in Table 4.

**Table 4.** Measurement campaign in worldwide

<b>Measurement Campaign (Country)</b>	<b>Frequency Range (MHz)</b>	<b>Average Occupancy Ratio (%)</b>
Spain	30-3000	22.57
America	30-3000	17.4
China	440-2700	15.2
England	300-4900	13.8
Vietnam	20-3000	13.74
Romania	25-3400	12.19
France	400-3000	10.7
India	700-2700	6.62
New Zealand	806-2750	6.21
Turkey	25-3000	5.12
Singapore	80-5850	4.54
Qatar	700-3000	4.15

As can be seen from the results, it is possible to use the idle frequency bands for dynamic spectrum access. This shows that applications such as cognitive radio will deal with spectrum

usage problems and that idle frequency bands can be reused in the spectrum for emerging technologies. This will prevent both inefficient use of the spectrum and the high allocation fees. For this reason, cognitive radio studies are expected to become available worldwide in the near future.

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