Spectrum Occupancy Survey In HULL-UK For Cognitive Radio Applications: Measurement & Analysis

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Abstract: - *Efficient use of the radio spectrum is a necessity for future wireless systems. Cognitive Radio (CR) systems promise large increases in spectral efficiency. An important design constraint for systems is understanding of the current use of frequency bands which may be used by future CR systems. This paper describes a set of spectrum occupancy measurements performed in Hull, UK, in November 2012 and proposes long-term studies in a single location. Observations provide evidence that the licensed spectrum is far from fully utilized in frequency. Measurements provide evidence of the spectral efficiency benefits that may be accrued by the dynamic reuse of the available spectrum. Such improved usage could break the current spectrum availability bottleneck. The measurement method is based on the energy detection principle.*

Index Terms: - *Cognitive Radio, Spectrum Occupancy, Detection threshold, Data processing, Spectrum Measurement*

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1 INTRODUCTION

The radio spectrum is a finite, and arguably scarce, natural resource with many systems competing for spectrum in telecommunications bands. The demand for the radio spectrum is growing, particularly due to the increased demand for broadband wireless services. However, some recent spectrum measurements have demonstrated that most of spectrum, through allocated, is vastly under utilised.. The spectrum scarcity perceived today is due to the fixed allocation of spectrum and emerging bandwidth hungry wireless technologies. Recently auctions took place in various part of world for small portions of radio spectrum for 3G and 4G systems, and huge sums of money were paid to obtain licenses for exclusive spectrum use. The traditional spectrum allocation policy, which provides a fixed allocation to the license user, is successful in reducing interference but does not offer flexible and efficient utilization of radio spectrum. Cognitive radio (CR) systems offer the possibility of greatly increasing the potential of the allocated and unutilized spectrum of primary systems. Several spectrum occupancy measurements have been conducted worldwide. An old management adage that is still accurate today says “you can’t manage what you don’t measure”. Therefore, to estimate the degree of radio spectrum utilization in a geographical region, and hence to consider principles of actual radio spectrum management, a campaign of experimental measurements has been conducted. The basic principle of CR is to allow unlicensed opportunistic spectrum access (OSA), where time and location allow it.

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Licensed frequency bands can be used provided that no harmful interference is caused to the licensed users. Dynamic spectrum usage is a new option that is radically different from current spectrum management practices which focus on granulating the spectrum. One of the main motivating factors attributed to the growth of research in CR is the current worldwide migration of TV broadcasting from analogue to digital systems. This liberates valuable spectrum. An application of CR that would greatly contribute to increased spectral efficiency is to allow unlicensed users to access, in a carefully controlled manner, the licensed bands. In order to avoid any harmful interference to the primary (licensed) system, CR equipment should include the essential functionality specified in the next subsection.

a - Cognitive Tasks: An Overview

Opportunistic access by unlicensed users to licensed bands is a CR feature that would greatly contribute to increased spectral efficiency. In order to avoid any harmful interference to the primary (licensed) system, CR equipment should include the following functionality:

- Frequency-agility and re-configuration of radio;
- Spectrum sensing;
- Primary system detection and interference avoidance;
- Spectrum management to achieve effective co-existence and radio resource sharing.

An understanding of current spectrum usage patterns is vital for regulators to define efficient dynamic spectrum methodologies.

b. Contribution of this Paper

In this work, we investigate the spectrum utilization of a range of communications bands at the geographical location of the University of Hull (UK). The 12-day measurement campaign was undertaken on the roof of the Applied Science building covering the frequency range from 180 to 2700 MHz. Measurements of the radio environment can provide valuable insights into current spectrum usage provided scan time and bandwidth resolution are chosen appropriately.

c. Organization of this Paper

The paper are organized as follows First, section 2 describes the spectrum activity measurement; Section 3 describes the measurement location and equipment used; Section 4 describes the measurement setup; Section 5 describes the data processing, leading to the determination of occupancy metrics, spectrum occupancy and duty cycle . Section 6 illustrates the detection of threshold. Analysed and results are presented in section 7 and 8. Finally, section 9 summarizes the conclusions and describes planned future work.

2 SPECTRUM ACTIVITY MEASURMENT

Measurements of spectrum occupancy have been an important research topic in the field of CR, providing an insight into the amount and portions of spectrum that might be available to future CR deployments by assessing existing usage. Several measurement campaigns covering both a wide frequency range [1] as well as some specific licensed bands [2] have already been performed in diverse locations and scenarios, in order to determine the degree to which allocated spectrum bands are occupied in real wireless communication systems. However most of them were carried out in the USA including San Francisco [3], Denver [4] and San Diego [5]. Additionally, several broadband spectrum surveys were conducted in New Zealand [6], Singapore [7], Germany [8], the UK [9] and Spain [10]. These survey reports show the maximum, minimum and average measured power level in received signals in different bands. The research work in spectrum activity measurements worldwide has involved either short or long-term measurement. Short time measurement campaigns (e.g. for hours or a maximum of a few days) have looked at the percentage of spectrum bandwidth occupied [11], and permanently available "whitespace" spectrum, rather than the temporal nature of channel occupancy. Long-term measurements are of duration greater than 10 days and up to several months where the results focus on spectrum availability for long periods (whitespace) rather than performing temporal analysis of the activity measured. A study commissioned by the UK Regulator OFCOM [12] described results of 5 months of measurements in the range 10MHz – 5GHz. The number of measurement locations used to date can arguably be considered as insufficient. The decision to deploy CR systems over a wide scale cannot be based on conclusions derived from studies conducted in a few geographical areas under specific spectrum regulations. Further spectrum measurements are therefore required, which motivates our spectrum measurement campaign.

3 MEASURMENT LOCATION AND EQUIPMENT

The measurements were performed on the roof top of the Applied Science building at the University of Hull. This measurement site (GPS location latitude 53.74° North, longitude 0.34° West) has direct line-of-sight with several FM transmitters, analogue and DVB-T transmitter, GSM and UMTS base stations. Various base stations and telecommunication systems are already hosted in the University, particular GSM and UMTS base stations which were a few tens of meters away from the measurement location. The equipment used was Bilog Antenna CBL 6143 with a frequency range of 30 to 3000 MHz, which fed the received signal to an Agilent E4407B spectrum analyzer. The spectrum analyzer converted the received signal into power versus frequency traces using an internal mixer, sampler, and a computational Fast-Fourier Transform (FFT) engine. The traces collected from the spectrum analyzer were transferred to a desktop computer by a general purpose interface bus (GPIB), where the raw data was stored. This data was later processed using MATLAB to estimate the occupancy statistics and to produce time-frequency occupancy plots. The measurement equipment employed in this study is illustrated in Figure 1.

Fig 1. Measurement equipment employed in this study: Antenna, Spectrum Analyzer and Computer

4 MEASURMENT SETUP

The main configuration parameters for the spectrum analyzer are listed in Table I. The measurement frequency range was divided into several blocks according to the local spectrum allocations and taking into account the transmitter signal bandwidth for each band. For example, GSM/DCS bands were measured with frequency spans of 45 MHz, which results in a frequency bin of 45 Hz//(551–1) = 81.8 kHz i.e, narrower than the 200 KHz RF bandwidth of GSM/DCS signal. Similarly, 727.3 KHz and 745.5KHz bins were employed to measure TV bands (8 MHz bands) and UMTS band (5MHz RF bandwidth) respectively. An each block was measured over a 24 hour interval.

TABLE I- SPECTRUM ANALYZER CONFIGURATION

Parameter	***Value***
Frequency Range	*180- 2700 MHz*
Frequency blocks/Frequency bins	*Variable (45-600)/(81.8-1090.9 kHz)*
Resolution (RBW/VBW)	*30 kHz/ 30 kHz*
Sweep time	*Auto(selected by the SA)*
Reference Level	*-20 dBm*

5 DATA PROCESSING

This section describes the steps taken to produce the spectrum occupancy as shown in Figure 2. The numerical computational package MATLAB was used for all processing after the signal capture. The whole process consists of four steps: raw data input, adaptive threshold setting, calculating the duty cycle of each channel and calculating the average duty cycle of the spectrum band

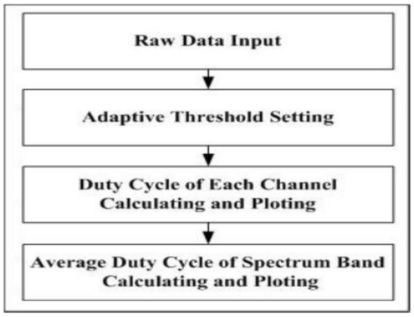

Fig 2. Data Processing Procedure

Raw data input

The data are the received power level values in dBm at the antenna output without any processing. The data measurement are collected into a *M by N* matrix, with elements $P_{fm,tn}$ as

$$\begin{bmatrix} P_{f1,t1} & \cdots & P_{f1,tN} \\ \vdots & \ddots & \vdots \\ P_{fM,t1} & \cdots & P_{fM,tN} \end{bmatrix};$$

Where f_m denotes the frequency or channel and t_n records the time slot.

Adaptive threshold setting

As each channel has a different noise power level, a threshold will be set for each band respectively. When the receive power is higher than this threshold a channel will be considered to be occupied and unavailable for use by a CR system.

Duty cycle (Measured occupancy)

Duty cycle indicates how often the signal is seen on each channel during a sample period. The duty cycle is defined as the percentage of time a channel is occupied. Given a time-series of channel power measurements, the duty cycle can be calculated using:

$$\text{Duty Cycle} \equiv \frac{\text{Signal Occupation Period}}{\text{Total Observation Period}} \times 100\%$$
$$= \frac{n_s t}{T} = \frac{n_s t}{Nt} = \frac{n_s}{N}$$

Where *t* denotes the interval of time (a.k.a. a slot) during which a channel is monitored during a frequency sweep, T is total measurement duration, n_s is the number of slots in which a channel was deemed to be occupied, and N denotes the total sweeping times of the channel.

Average duty cycle of spectrum band

The band spectrum occupancy is defined to be the average duty cycle of the channels within a band. The equivalent amount of band spectrum occupied is then the product of the band spectrum occupancy and the bandwidth.

6 DETECTION THRESHOLD

A number of different methods are proposed for identifying the presence of signal transmissions. In some approaches, the signals within a channel are analysed to determine signal type, along with channel occupancy. Many methods have been proposed for CR systems to determine whether a channel is occupied or available for opportunistic access. These include Energy detection (ED) method [13], Matched filtering (MF)-based method [14], Cyclostationary detection method [15], Multitaper spectrum estimation [16], Wavelet transform based estimation [17] .Only energy detection methods do not require any prior knowledge of the signal. This is the method used in order to evaluate the occupancy in the several frequency bands which presented in Table II. An important aspect of measurement is the determination of a suitable detection threshold. Selecting the threshold at too low a value will increase the probability of false positives i.e. deciding a channel is occupied when it is not. This could caused by high power noise samples and lead to overestimation of channel occupancy. On the other hand, if the threshold is chosen too high, weak signals may be treated as noise and this would result in an underestimation of the actual occupancy. Although, the threshold setting is a current and active area of research, two main approaches exist, namely an empirical and an analytical method. ITU recommendation [ITU Handbook Spectrum Monitoring, p. 168]: the threshold should be 10dB above the ambient noise. The optimal choice of threshold depends upon the relative costs of false positive and false negative detections. For the current study, 5 dB above the average received signal power recorded in an observed band during 24h over 12 days is a compromise that allows detection of the weakest measured signal and yet is high enough to avoid false detection.

7 ANALYSIS OF SPECTRUM OCCUPANCY

Before moving to band by band spectrum occupancy analysis, in Figure 3, we show the received power versus frequency plot for the whole frequency range of the measurement study (180 MHz to 2700 MHz). Based on this overview and following the local spectrum allocations, the entire frequency range can then be divided into smaller blocks/spans. The frequencies below 900 MHz is primarily allocated for broadcast communication. Because of the nature of the high power broadcast channels, the communication channels were easily detected by the equipment. It is interesting to note that the band below 1 GHz appears to some extent occupied, despite the fact that the band above 1 GHz appears to be unoccupied. While the band below 1 GHz may be fully occupied, we know that many of these legacy broadcast systems are not the most efficient users of spectrum (television and radio can benefit from modern digital compression) and many include carrier waves which convey no information but are necessary for demodulation. In the low portion of the band the high occupancy figure may not correlate to efficient utilization. On the other hand, the low occupancy figures above 1 GHz may not necessarily mean that the spectrum is unutilized; it only means the activity (if there was any) was undetectable by the instrumentation.

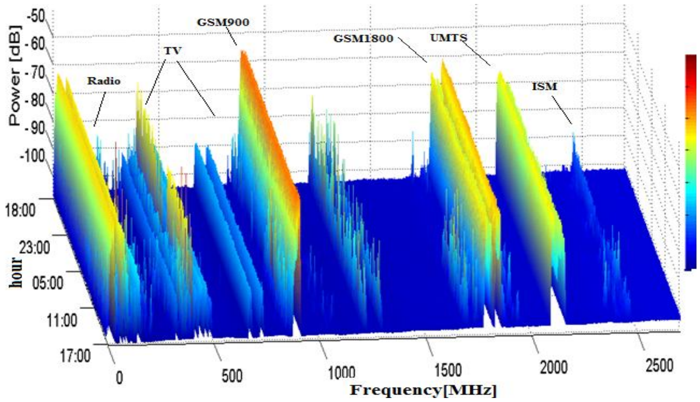

Fig 3. Received power versus the frequency band (80MHz-2700MHz) for 24 hours
Start time 10/29/2012 18:00 & Stop time 10/302012 18:00

Although it indicates that overall spectrum utilization in the whole frequency range of our study might very low, it does not give us a detail picture of how spectrum is utilized in different bands allocated to different services. Therefore, for a better view of the band by band occupancy pattern, we will consider selected bands in more detail.

a. The 180-400 MHz Frequency Band

The data for this band is shown in figure 4. The occupancy percent was measured for 180 to 400 MHz , however most of this band is, for the moment, licensed for military applications, with average duty cycle 6.9%. Other channels, such as the radio astronomy channels, must maintain radio silence to allow these observational instruments to operate. Satellite communications may not be detected by our system as the antenna is orientated horizontally.

b. The 470-850 MHz Frequency Band

Several TV broadcasting stations can be noticed in figure 4 (frequency band 470-720 MHz). The power level of some of stations is higher than others, as the transmitter is located closer to our building where the measurement was performed. The mount of occupancy is quite low, this might due to the staged transfer of TV broadcasting to digital systems. The DVB-T signals can be seen in figure 5 at 582 MHz(channel 22), 514 MHz (channel 26) , 530 MHz channel (28) and 560 MHz channel (30). In the frequency band 720 to 850 MHz, only two channels were detected during measurement, broadcast station (730 MHz, channel 53) and broadcast station (785, channel 60). Over all, we can see that average duty cycle of this band is 13.46%.

c. The 880-960 MHz and 1710-1880 MHz Frequency Band

Figure 6 and figure 6 shows the occupancy for the GSM900 and GSM1800 bands respectively. These two bands have average occupancy of 32.91% and 24.64% respectively. Note that the occupancy of the uplink and downlink bands is not identical. A similar occupancy pattern has been observed in the uplink and downlink band of 3G services as can be seen in figure 7. This result can be explained as follows. The control channels for GSM900, GSM1800 and WCDMA are constantly being broadcasted by the base stations on the downlink (DL), thus the DL for these frequencies seems fully occupied as they are always transmitting with relatively high power. The uplink, on the other hand, for cellular systems, is based on active user communication through the network. If there is no active communication, there are still some periodic short-pulse transmissions on the uplink for location updating procedures which are too short to be picked up by analyzer. Also note that GSM900 mobile stations have a higher transmit power than GSM1800, which explains the higher peaks picked up by analyzer. From figure 8, it may be observed that the 3G uplink is apparently totally unoccupied. The use of WCDMA modulation spreads signals across the band with very low output transmission power. The 3G signals have been interpreted as band specific noise and so not detected by the threshold detection method.

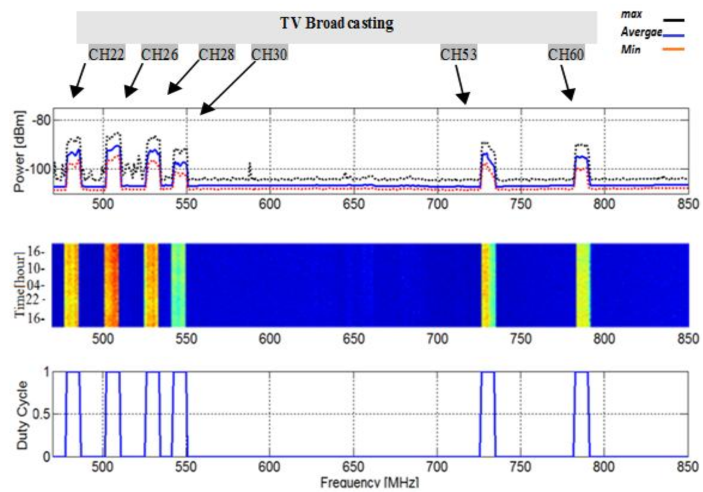

Fig 5. Occupancy measurement from 470MHz to 850MHz

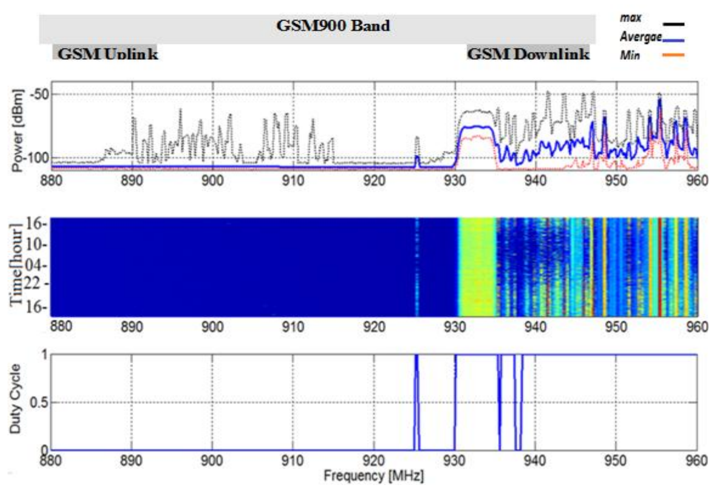

Fig 6. Occupancy measurement from 880MHz to 960MHz

d. The 1900-2500 MHz and 2500-2700 MHz Frequency Bands

Looking at figure 8, it appears that the most bands from 1900 to 2500 MHz are unoccupied, except for the UMTS and ISM bands. Average duty cycle of this band is 9.47 %. However, the occupancy estimates of these bands might not be the representative of the actual occupancy. These results could be explained as follows: WBA signals might not be detected at the measurement point if the access points are close enough, satellite signal power might be much lower than the ambient noise when it reaches the ground, and the short wavelength c ISM band signals cannot penetrate through walls and so ma be contained within buildings. Additionally, the frequency ban (2400-2483 MHz) is used by well-known unlicensed industria scientific and medical (ISM). Devices in this band includ microwave ovens, cordless phones, wireless networks an wireless instrumentation devices. The spectrum plot indicate that the band is used, but the occupancy (duty-cycle) figure i low. That may be due to the location of the receiver 100 fee above the ground. Also there may have been low activity in th time period under study. The frequency band of 2500 to 270 MHz appears completely unused at this point. The occupanc estimates of these bands might not be the representative c actual occupancy due to points such weak signal and buildin penetration.

8 RESULTS AND MAIN OBSERVATION

In this section, we summarize the major observations from th occupancy results of this study and identify the channels fc long term studies in order to provide policy markers with the information necessary for regulating dynamic spectrum access technologies such as cognitive radio. Graphical presentations of the band by band average spectrum occupancy, as well as the average spectrum occupancy for the whole spectrum range studied, are shown in Table II. The plot of average occupancy, for the whole 180 MHz to 2700 MHz frequency range, is determined as follows. First we determine the average spectrum usage (in MHz) of each band as shown in Table II by multiplying the average occupancy of each band by its corresponding bandwidth. For example, average spectrum usage of 850 to 470 MHz band is 0.1346X (850-470) =51.148MHz. Then, summing the spectrum usage of all bands and dividing it by the total available bandwidth 2700-80=2620 MHz, we get the average spectrum occupancy of 11.02 % for the whole spectrum range studied.

TABLE II- AVERAGE DUTY CYCLE STATISTICS

<table>
<tr><th>Frequency range (MHz)</th><th colspan="3">Average duty Cycle (Measured occupancy %) <u>Threshold 5dB above average</u></th></tr>
<tr><td>180-400</td><td>6.9%</td><td rowspan="3">12.4%</td><td rowspan="6"><u>11.02%</u></td></tr>
<tr><td>470-850</td><td>13.46%</td></tr>
<tr><td>880-960</td><td>32.19%</td></tr>
<tr><td>1710-1880</td><td>24.64%</td><td rowspan="3">9.9%</td></tr>
<tr><td>1900-2500</td><td>9.4%</td></tr>
<tr><td>2500-2700</td><td>0%</td></tr>
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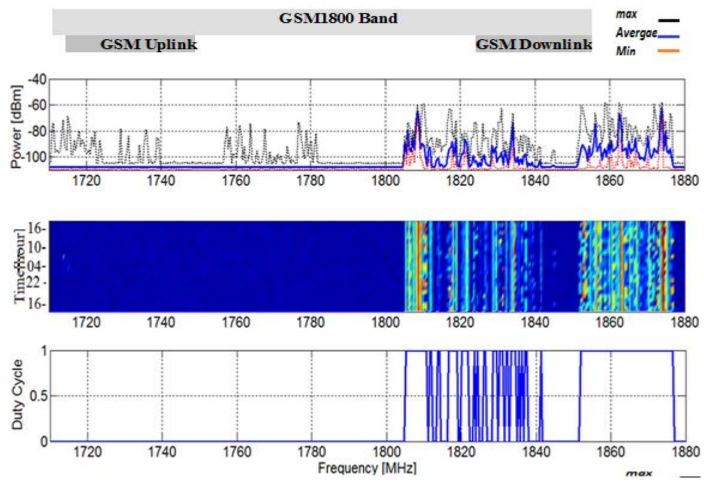

Fig 7. Occupancy measurement from 1710MHz to 1880MHz

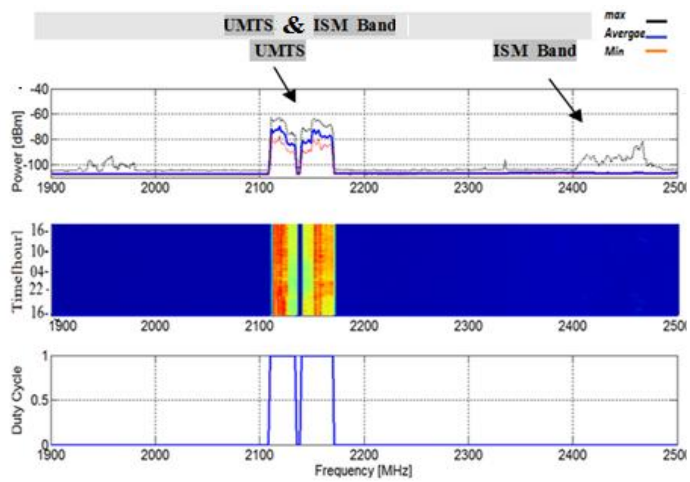

Fig 8. Occupancy measurement from 1900MHz to 2500MHz

Now using Table II and the results of section VII, the following useful information can be extracted:

- The highest occupancy has been observed in the GSM900 and GSM1800 bands due to broadcasting downlink.
- Low occupancy has been observed in the bands allocated for fixed/mobile services, and primary and secondary radar.
- The bands allocated for aeronautical radio navigation, fixed satellite, WBA and ISM appear to have low utilization. Also, TV bands provide interesting opportunities for secondary usage.
- Frequencies above 1GHz are relatively underutilized except for the cellular bands.

Although some frequencies in some bands appeared to be used, the duty cycle is quite low.

9 CONCLUSION

The work described in this paper covers a set of long term observations of spectrum occupancy measurement conducted in 180 - 2700 MHz band, and associated analysis, in the urban area of Hull City, UK. The main aim of the work have been to discover which bands might be suitable for cognitive radio. Methods for the detection and exploitation of spectrum holes, based on observation of the radio environment, are essentail for an efficient use of spectral resources. The results obtained during the measurement campaign demonstrate a significant amount of unused spectrum in these bands, especially in TV band region, as well between 1 GHz and 2 GHz, except for the GSM1800 band. The unused spectrum could potentially be available to future development of cognitive radio. Overall, the mean occupancy ratio over whole band was as low as 11.04 %. To determine more objective spectrum utilization, additional and more sophisticated methods will have to be employed and other locations will have to be analyzed. Although the results obtained up to now were collected exclusively in an urban environment, further measurement campaigns targeted at suburban and rural environments are intended, in order to obtain a complete picture of the perspectives for future cognitive radio application.

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