Spectrum Occupancy Measurements and Lessons Learned in the Context of Cognitive Radio

M. Mehdawi, *Member, IEEE* , N. G.Riley, M. Ammar, A. Fanan, and M. Zolfaghari

Abstract — **Various measurement campaigns have shown that numerous spectrum bands are vacant even though licenses have been issued by the regulatory agencies. Dynamic spectrum access (DSA) based on Cognitive Radio (CR) has been regarded as a prospective solution to improve spectrum utilization for wireless communications. Empirical measurement of the radio environment to promote understanding of the current spectrum usage of the different wireless services is the first step towards deployment of future CR networks. In this paper we present our spectrum measurement setup and discuss lessons learned during our measurement activities. The main contribution of the paper is to introduce global spectrum occupancy measurements and address the major drawbacks of previous spectrum occupancy studies by providing a unifying methodological framework for future spectrum measurement campaigns.**

Keywords—**Cognitive Radio, Duty Cycle, Spectrum Occupancy Measurement, Spectrum Utilization.**

I. Introduction

THE command and control approach to spectrum regulation can be shown to result in inefficient spectrum utilisation. Before we attempt to assess the potential improvement available through use of Cognitive Radio (CR) we need to understand and recognise the actual occupancy of the licensed bands. Detailed and long term spectrum occupancy campaigns provide understanding and prediction of primary user activity, which is considered an essential step toward improving accuracy and decision making processes in cognitive radio. Actual measurements clearly show that the licensed spectrum is underutilised continuously across time and space; many white spaces which are not utilised may be identified readily [1]. Although previous spectrum measurement campaigns followed broadly similar approaches, a detailed analysis reveals the lack of a common and appropriate evaluation methodology. As pointed out in [2], different measurement strategies can result in widely divergent answers. Therefore, the availability of a common and reliable evaluation methodology would be desirable not only to prevent inaccurate results but also to enable the direct comparison of results from different sources and different campaigns.

Meftah Mehdawi, School of Engineering, University of Hull, Cottingham Road, HU6 7RX, UK (email: Maftahmahdwi@yahoo.com)
N. Riley, School of Engineering, University of Hull, Cottingham Road, HU6 7RX, UK (email: N.g.riley@hull.ac.uk)
A. Fanan, School of Engineering, University of Hull, Cottingham Road, HU6 7RX,UK (email: email: Anuarfanan@yahoo.com)
M. Ammar, School of Engineering, University of Hull, Cottingham Road, HU6 7RX, UK (email: Mahmod_Aammar@yahoo.com)
M. Zolfaghari , School of Engineering, University of Hull, Cottingham Road, HU6 7RX, UK(email: M.zolfaghari@2009.hull.ac.uk)

Furthermore, several important practical aspects need to be carefully taken into account when evaluating spectrum occupancy. The key objective of this paper is to introduce global spectrum occupancy measurements and to mitigate the major drawbacks of previous spectrum occupancy studies by providing a unifying methodological framework for future spectrum measurement campaigns.

The rest of the paper can be grouped as follow: In section II we give an overview of global spectrum occupancy measurements. Section III discusses lessons learned during these measurements, which involve various factors to be considered when defining strategies for specific radio spectrum measurements such as the influence of antenna selection, the influence of the spectrum analyser and influence of frequency and time dimensions. Finally, section IV summarises the conclusions.

II. Global Spectrum Occupancy Measurement (Previous Campaigns)

Summarising the results of measurement campaigns for spectrum utilisation involved examining several spectrum surveys covering a wide frequency range at different locations and scenarios to determine the actual spectrum utilisation. Several spectrum surveys have been conducted with some covering a wide frequency range and some more specific to a particular radio technology. For greater detail [3] summarizes previous spectrum measurement and the main technical aspects of various broadband spectrum measurement campaigns. This section reviews some of the campaigns performed in different parts of the world in the context of cognitive radio application. The first spectrum occupancy measurement campaign to be considered here was achieved in USA by the National Telecommunication and Information and Administration (NTIA) [4]. The next large scale spectrum occupancy measurement was done by Marc McHenry and funded by the National Science Foundation (NSF). The occupancy in many American cities was found to be always below 25% and it is suggested that this is due to the higher detection threshold used, between -90 and -105 dBm. Robin Chiang et.al conducted spectrum occupancy measurement in New Zealand [5]. This campaign, conducted in the frequency range between 806 MHz and 2750 MHz, indicated that, on average, the actual spectral usage in this band is only about 6.2%. The average occupancy for the band 80 MHz and 5850MHz was found to be only 4.5% in the spectrum survey of Singapore [6]. The spectrum occupancy measurements conducted in the frequency range from 75 MHz to 3 GHz in an outdoor urban environment of Barcelona, Spain is presented in [7]. The measurements are analysed and compared to the official spectrum regulations. A common finding among these studies is that a significant amount of spectrum available is indeed heavily underutilised at the moment

III. Lesson Learned During Measurements Setup

There are various factors to be considered while defining strategy for specific radio spectrum measurements which are mentioned in [2, 9, and 10]. Some of these are basic parameters that every spectrum measurement strategy should clearly specify: frequency (frequency span and frequency points to be measured), resolution bandwidth, location (measurement site selection), direction (antenna pointing angle) and time (sampling rate and measurement period). The study presented in this paper is based on a spectrum analyser setup where an external device is added in order to improve the detection capabilities of the system, which leads to more accuracy and reliability. A detailed scheme is shown in Fig.1. The measurements were performed on the roof top of the Applied Science building at the University of Hull, UK. The design is composed of four broad band antennas covering the frequency from range from 30 to 3000 MHz, and a low noise preamplifier to enhance the overall sensitivity and the ability to detect weak signals, and spectrum analyser connected to a computer to record the spectrum activity data. In the next subsections the influence of antenna selection, influence of spectrum measurement and influence of frequency and time aspects will be introduced in more detail.

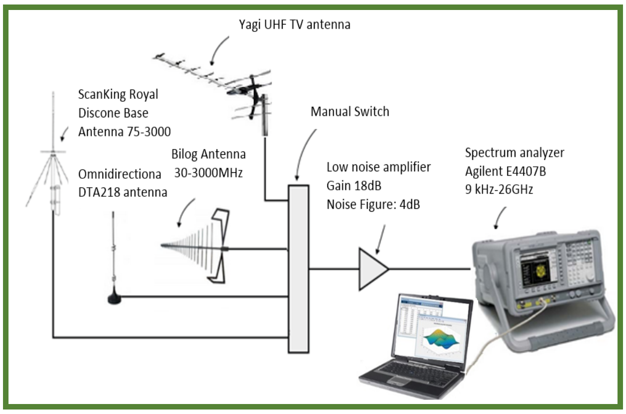

Fig. 1. Measurement Setup

A. Influence of Antenna Selection

Antenna selection can be one of the most confusing parts of designing a spectrum measurement platform. The two core types of antennas are omnidirectional and directional. In the course of choosing the optimal antenna we always find ourselves comparing manufacturer's specifications. An alternative approach is to simply compare the measured signal levels of one antenna to another. In the following experiment we compare the relative field performance of four antennas and choose the most suitable and accurate. The general characterisation of the traffic density at the TV frequency bands with different antennas is described in this section. The spectrum occupancy measurements have been conducted with four different antennas, to investigate the effect of the antenna on the spectrum activity a cross whole TV band and with specific TV channels. The first and second measurements were conducted using Discone antenna and DTA218 Digital antennas, respectively, which are considered as omnidirectional antennas. The third and fourth measurements were conducted using Yagi antenna and Bilog antenna, respectively, which are considered as directional antennas. We compare the performance of received signals measured over the TV band using the four antennas as shown in Fig. 2. As expected, a higher received signal is observed with directional antennas than the omnidirectional antennas. A significantly higher spectral activity is observed by using an external amplifier for both the directional antennas and omnidirectional antennas. We have also noted that the duty cycle (DC) of spectrum occupancy of the TV band (470-862 MHz) using the Bilog antenna is greater than with the other antennas. This may be due to another channel being received from another broadcasting aerial since that antenna combines electromagnetic characteristics of both biconical and log periodic antennas into one assembly.

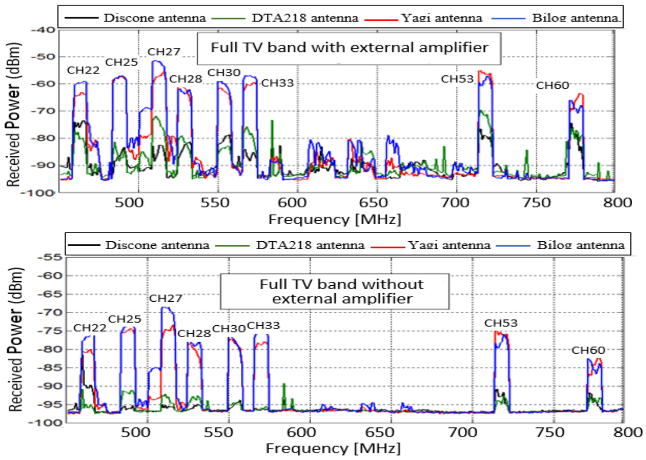

Fig. 2. Average Received Signal with/without External Amplifier over the Full TV Band.

Firstly, the analysis compares the Discone antenna (2.2dBi gain) with DTA218 antenna (3.5dBi gain). We see that the omnidirectional DTA218 has high received signal, since the received signal is 2-4 dB higher at CH 33(and at the rest of the TV channels). Secondly, the analysis compares the Bilog Antenna (6-7dBi gain) with the Yagi UHF TV antenna (12.5dBi gain). Both are models of directional antenna and capable of measuring the complete TV frequency band. Although the Yagi has 5-6dBi gain more than Bilog antenna, the Bilog antenna received high power, since this received signal has a 4 dB higher. Moreover, the Bilog antenna has about 3 to 4 dB high received power than the Yagi UHF TV antenna across the majority of the TV band spectrum as shown in shown in Fig. 2. One exception is at CH53 and CH60, where the Bilog received power slightly drops off at the low end, but at the high end the measured channel responses where similar. Taking into account all the received signal power over all TV channels with and without external amplifier we could conclude that the Bilog antenna sensitivity compares well to the others.

Generally, our system comprises four broadband receiving antennas, which are wideband antennas with directional and omnidirectional receiving patterns. The exceptionally wideband coverage (allowing a reduced number of antennas in broadband spectrum studies) and the omnidirectional feature (allowing the detection of licensed signals coming from any directions) make Bilog and DTA218 antennas attractive for radio measurement and monitoring applications. In this studies, directive antennas e.g., Bilog antennas may be used at fixed locations to improve the system's sensitivity at the cost of an increased complexity in the measurement procedures. However, to reduce complexity where a secondary user needs to detect licensed signals coming from any direction and different locations positions to avoid interference with the primary user, and the DTA218 omnidirectional antennas are preferable.

1-Influence of Frequency Dimension

The two main frequency dimension parameters are: Frequency range and Resolution Bandwidth (RBW). Firstly, in order that no signals will be missed by skipping over them in frequency, the band must be scanned in steps smaller than the resolution bandwidth. In previous spectrum measurement campaigns, the relation between the frequency range and signal bandwidth has received little attention. However, to achieve results with reasonable accuracy classifying emissions in bands with different channel widths this is important. Selecting a Frequency Bin (FB) size narrower than the signal bandwidth can give better accuracy results. Examples are measurement of GSM1800 and the UMTS downlink bands shown in Fig.3 and Fig. 4 respectively. In the case of GSM1800, higher FB tend to result in higher observed spectrum occupancy rates, as seen in Fig.3 and Fig.4. But, the behaviour in each case is different. In the case of the GSM1800 band, for frequency bins lower than the bandwidth of the transmitted signal (200 kHz), the average Duty Cycle "DC" (53.02% and 61.52%) indicate that the band is subject to moderate usage levels. For a frequency bin of 1.250 MHz, which is quite greater than the signal bandwidth, the obtained DC of 82.35% incorrectly concludes that the same band experiences a high level of utilisation.

This phenomenon can be clarified as follows. Frequency bin values (e.g. frequency bin of 1250 kHz) larger than the signal bandwidth (200 kHz active channel) lead to important overestimations of spectrum occupancy in regions with moderate activity levels, which in turn results in greater average DC for the entire band. In the case of UMTS the studies where the frequency bins are always lower than the signal bandwidth (5 MHz), the average DC increases with the frequency bin, and the difference is less significant (only 9.43% between 79.05kHz and 1250 kHz), as shown in Fig. 4. This difference can indeed be qualified to the fact that for the lower frequency bins some frequency points lie within the UMTS channels' guard bands, where the DC is zero. As a result we could recognise that 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.

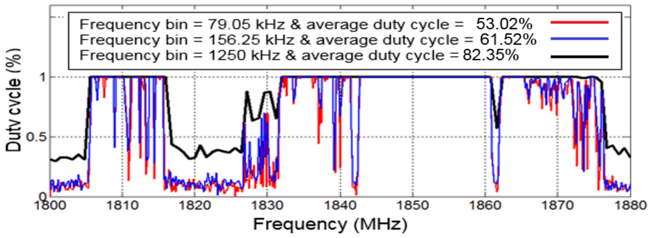

Fig. 3. Influence of the FB on the Activity GSM1800.

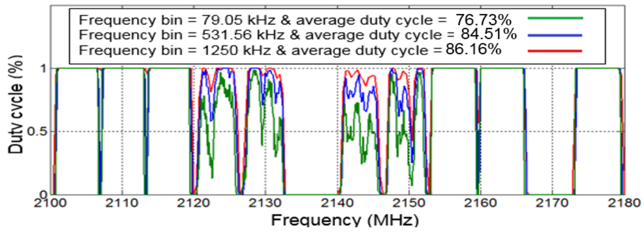

Fig. 4. Influence of the FB in on the Activity Band UMTS.

A second parameter is based on consideration of Resolution Bandwidth (RBW). Narrowing the RBW increases the system's ability to resolve signals in frequency and decreases the noise floor, which in turn improves the ability to detect weak signals at the cost of increased measurement times. Table 1 shows the influence of the resolution bandwidth on the activity in the band between 137 and 400 MHz. This band represents transmission from several radio systems with various signal bandwidths, such as private mobile radio networks (12.5/25 kHz), wireless microphones (200 kHz) and digital audio broadcasting (1.54MHz). From Table 1 we could conclude that a 10-kHz RBW can be considered as an adequate trade-off between detection capability (represented by the average DC) and measurement time (represented by the average sweep time). For instance, the 10kHz RBW configuration only misses the detection of 22.05%–19.41=2.6% of licensed signals with respect to the 3kHz RBW configuration while it is able to capture 12.745s/1.147s=11.17 times more PSD samples within the same measurement period. Wider RBWs result in shorter average sweep times but higher estimation errors, up to 18.42% for the 300 kHz RBW configuration. Based on the table results and observations, 10 kHz RBW can be considered as the most suitable choice for broadband spectrum research, offering trade-off between detection capability and required measurement time.

TABLE 1: IMPACT OF THE RBW ON THE ACTIVITY DETECTED BETWEEN 137 MHZ AND 400MHZ.

RBW	*Average duty cycle*	*Average sweep time*
1kHz	27.13%	114.73s
3kHz	22.05%	12.74s
10kHz	19.41%	1.14s
30kHz	14.01%	1.77s
100kHz	12.81%	11.47ms
300kHz	8.71%	5.5ms

2-Influence of Time Dimension

Time-domain analysis of spectrum measurements shows how a signal changes over time and is commonly defined by two parameters, sampling rate and the measurement period. Although sampling rate is controlled by the measurement device, measurement period can be easily controlled manually. Very different measurement periods have been considered in previous spectrum measurement campaigns, as it can be appreciated in [3]. The selected measurement period depends on the trade-off between the overall time required to complete the measurement campaign and the particular objectives of the measurement study. Some previous studies have been aimed at identifying spectrum usage patterns over long periods and understanding any potential seasonality in the visible spectrum usage. In former measurement campaigns different periods have been considered. For instance [8], suggested long-term measurement campaigns with measurement periods of several years to identify spectrum usage patterns over long periods. On the other hand, by considering the issue of resource utilisation the short-term evaluation and classification of spectrum usage is frequently more interesting since in practice it has impact on the behaviour and performance of cognitive radio. In such a case, long-term measurements are not necessary. In the context of cognitive radio we need to know how long spectrum should be measured to obtain a descriptive estimate of the actual spectrum usage. In order to answer this question the effects of the measurement of the TV band (CH22) and GSM900 was examined with time period of 1 hour, and of 24 hours. Result obtained during measurement campaign are different in these bands as shown in Fig. 5.

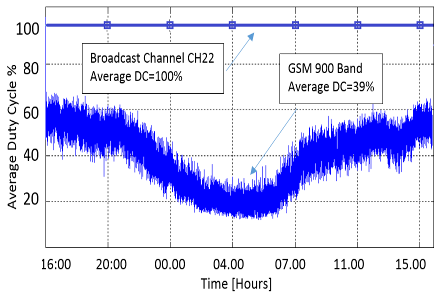

Fig. 5. Average DC for TV Broadcasting and GSM Band.

The utilisation of the TV band (CH22) indicate that the average DC for entire measured frequency point was closer to 100% as expected. This is because most occupancy data in our measurement bands (CH22 TV Channel) are stationary which do not vary with time and hence the instantaneous DCs matches the average value at every time instant. This conclusion is valid not only for TV but in general for transmitters with a constant temporal activity. However, GSM band exhibits an oscillating behaviour over time. When the entire band is considered, the instantaneous DC then notably differs from the average value. The utilisation of the GSM900 MHz band varies with time throughout the day. The minimum value was between 23:00 and 6:00 with an average DC of 19% to 21% while measurements between 16:00 and 22:00 report average DC of 50% to 60%. The average DC usage of band over the 24-hours is 39%. Overall, data show that the 24 h seasonal pattern is caused by the peak traffic of each day in 11:00–15:00 and 16:00–20:00 local time. Although the common monitoring durations are 24h, working hours or another appropriate period hours in order to account for potential daily temporal patterns, our investigations show that the optimum duration of monitoring depends on the purpose of the occupancy measurement and the available a priori knowledge about the behaviour of the radio systems using the spectrum resource.

IV. Conclusion

In this paper firstly we introduced overview of global spectrum occupancy measurements. Overall, the result shows that the level of spectrum utilisation is consistently low. The obtained results demonstrated the existence of a significant amount of spectrum which is potentially available for the future deployment of cognitive radio systems. Next, we have discussed spectrum occupancy measurement setups in detail and have elaborated on the major design decisions and lessons learned. This part presented a comprehensive and in-depth discussion of several important methodological aspects that need to be taken into account when evaluating spectrum occupancy such as the influence of antenna selection, influence of spectrum analyser, influence of spectrum measurement and influence of frequency and time aspects. The results presented in this paper highlight the importance of carefully designing an appropriate methodology when evaluating spectrum occupancy in the context of cognitive radio. The outcome of this paper will be of great utility in the study outlined in following researches.

References

[1] FCC. Spectrum Policy Task Force Report, ET Docket, Nov. 2002.

[2] R. J. Matheson, “Strategies for spectrum usage measurements”. *In Electromagnetic Compatibility, Symposium Record., IEEE 1988 International Symposium on* ,pp. 235-241,1998.

[3] M. Mehdawi, “Spectrum occupancy survey in Hull-UK for cognitive radio applications: measurement & analysis.” *International Journal of Scientific & Technology Research*, 2(4), pp.231-236, April 2013.

[4] F. H. Sanders, “Broadband spectrum surveys in Denver, CO, San Diego, CA, and Los Angeles, CA: methodology, analysis, and comparative results”. *In Electromagnetic Compatibility, IEEE International Symposium on* Vol. 2, pp. 988-993, August 1998.

[5] R. I. Chiang, G. B. Rowe, & K. W. Sowerby, “A quantitative analysis of spectral occupancy measurements for cognitive radio”. *In Vehicular Technology Conference, 2007. VTC2007-Spring. IEEE 65th* ,pp. 3016-3020, April 2007.

[6] M. Islam, H., Koh, C. L., Oh, S. W., Qing, X., Lai, Y. Y., Wang, C. & Toh, W. “Spectrum survey in Singapore: Occupancy measurements and analyses”. *In Cognitive Radio Oriented Wireless Networks and Communications, 2008. CrownCom. 3rd International Conference on* ,pp. 1-7, May 2008.

[7] M. López-Benítez, A. Umbert, &, F. Casadevall. “Evaluation of spectrum occupancy in Spain for cognitive radio applications”. *In Vehicular Technology Conference, 2009. VTC Spring 2009.* IEEE 69th ,pp. 1-5, April 2009.

[8] M. A. McHenry, P. A. Tenhula, D. McCloskey, D. A. Roberson. “Chicago spectrum occupancy measurements & analysis and a long-term studies proposal”. *In Proceedings of the first international workshop on Technology and policy for accessing spectrum* pp. 1-3, August 2006.

[9] M. McHenry, K.Steadman. “Spectrum occupancy measurements, location 2 of 6: Tyson’s Square centre, Vienna, Virginia”. *Shared Spectrum Company Report.* , April 9 2004.

[10] S. W. Ellingson,. “Spectral occupancy at VHF: implications for frequency-agile cognitive radios”. *In IEEE Vehicular Technology Conference* Vol. 62, No. 2, pp. 1379, September 2005.