Spectrum Occupancy Analysis for Cognitive Radio

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Abstract: Observations provide evidence that the licensed spectrum is by far not fully used neither in time nor in space. Cognitive radio, which can sense its environment and location and then alter its frequency, modulation and other parameters so as to dynamically reuse the available spectrum, could break the current spectrum availability bottleneck. The fundamental aspect to the success of such technology is the statistical properties of the spectrum occupancy, which forms the basis of the current project.

Compared with the traditional spectrum analyser a chirp sounder using digital generation can scan 250-MHz bandwidth, on the order of 4 ms repetition rate. This paper presents the basic working principle of the sounder system and some measurement results from both measurement techniques. Preliminary analysis of 2.4 GHz ISM band is presented to give some insight into the average occupancy rate, the distribution of signal levels and the availability of communication bandwidths.

1. Introduction

In the current frequency allocation strategy, under which the regulatory bodies in various countries (such as Ofcom in the UK, FCC in the USA), different bands are assigned to different services and licensees are then required to operate inside those bands. Moreover, fixed spectrum allocation, assigned to specific services, can not be accessed by non-licensed users, even if the non-licensed user transmission does not introduce any interference to the service. Observations provide evidence that usage of the licensed spectrum is by far not equilibrium neither in the time domain nor in the spatial domain. For example cellular network bands are overloaded in most parts of the world but amateur radio or paging frequencies are not in which the spectrum utilization depends strongly on time and place.

On the other hand, more and more technological alternatives, such as WLAN and WiMAX, are becoming available, it is increasingly difficult to find spectrum that can be made available either for new services or for expanding existing ones. As a result, the current frequency strategy has not been able to optimise the spectrum usage.

Cognitive Radio could in theory allow multidimensional reuse of spectrum in space, frequency and time, modulation and other parameters so as to dynamically reuse available spectrum, which could break the current spectrum availability bottleneck. A Cognitive Radio system senses and understands its local radio environment to identify temporarily vacant spectrum to operate in. Cognitive Radio would hop into unused bands of the radio spectrum and hop out again if a primary user of a band required that spectrum.

Although there are currently no Cognitive Radio systems in wide deployment, the technology holds so much promise that it has already become one of the hottest research subjects of regulatory bodies, academic and military sections. The fundamental aspect to the success of such technology is the statistical properties of the current spectrum occupancy, which forms the basis of this project.

2. MEASUREMENT EQUIPMENT

Since there is no knowledge about the transmission systems and signal types to be detected, only energy detection approach can be practically applied in spectrum listening. The choice of measurement equipment in general purpose energy detection is done by the spectrum analyser as shown in Fig.1 [1]. Most often, the spectrum analyzer is controlled by PC using GPIB interface for long term listening and transferring data.

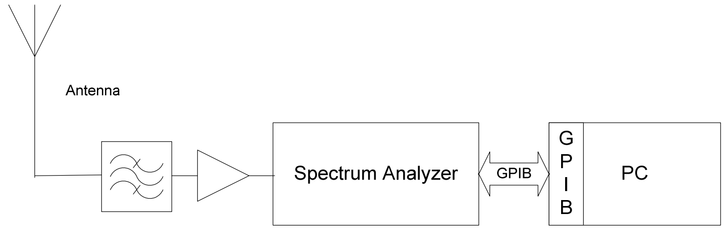


Fig. 1 Block diagram of the spectrum monitoring system.

While the spectrum analyzer facilitates spectrum measurement with wide bandwidth and its different detection modes and resolution bandwidths provide various parameters for modelling the spectrum occupancy, it is not very optimal in terms of noise performance and time response. Table 1 shows typical settings of a spectrum analyser for covering the ISM band. For example, for 1000 kHz resolution bandwidth setting, it needs 50 ms to scan the 83.5 MHz bandwidth with –80 dBm noise level, which higher than many communication signals. On the other hand, if we turn down the resolution bandwidth to 30 kHz, the corresponding noise level is now down to -95 dBm, but the sweep time will be increased to 700 ms.

Frequency Range	Resolution BW	Noise Level	Sweep Time
2400—2483.5	1000 kHz	-80 dBm	50 ms
2400—2483.5	100 kHz	-90 dBm	70 ms
2400—2483.5	30 kHz	-95 dBm	700 ms
2400—2483.5	10 kHz	-97 dBm	7000 ms

Table 1 Typical parameters of spectrum analyser setting.

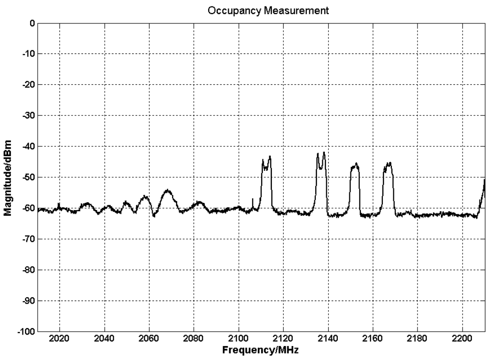
Moreover, an additional 1940 ms are needed to transfer 601-point samples to a PC with 300 k GPIB card. Under these conditions, it is difficult to catch low duty circle signals or frequency hopping signals.

Comparing the incapacity of the traditional spectrum analyser in the time domain, the sounder system [2] of Durham University can scan 250-MHz bandwidth on the order of 4 ms repetition rate, which is faster than the modern real time spectrum analyser. A wideband linear chirp signal up to 250 MHz bandwidth generated by the sounder system will be mixed with the occupancy signals and then the corresponding frequency components will be captured by the 250 kHz IF filter. After passing through signal conditioning, the IF signals are digitised and stored using the data acquisition unit. For example, Fig.2 shows that a 200 MHz spectrum occupancy data from 2010 MHz to 2210 MHz has been respectively measured by the sounder and spectrum analyser, from which we can clearly distinguish 4 UMTS CDMA signals and some patterns omitted by the spectrum analyser.

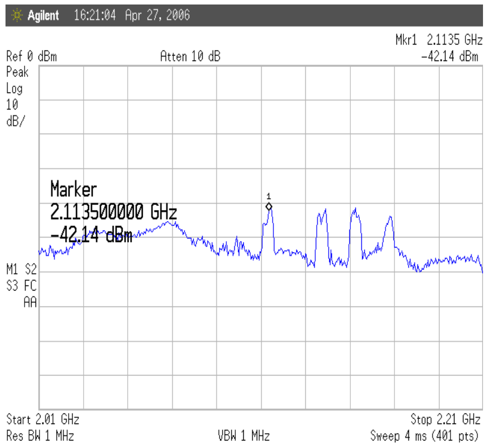
Since the sounder system is originally used for inspecting MIMO channels, with antenna array it also provides the additional directional occupancy information, which is an important parameter for modelling spectrum occupancy.

3. STATISTICAL ANALYSIS OF ISM BAND

In this section, we consider the 2400-2483.5 MHz industrial, scientific and medical unlicensed band, as an example to illustrate the statistical characters of spectrum occupancy. Currently, this band is used for license-free error-tolerant communications applications such as wireless LANs, Bluetooth and most microwave ovens, which use 2.45 GHz. Measurements of 15 scans every 2 minutes, were performed using a spectrum analyser to study the stationarity of occupancy. Figure 3 shows sweeps 1 and 10 with the different threshold levels.

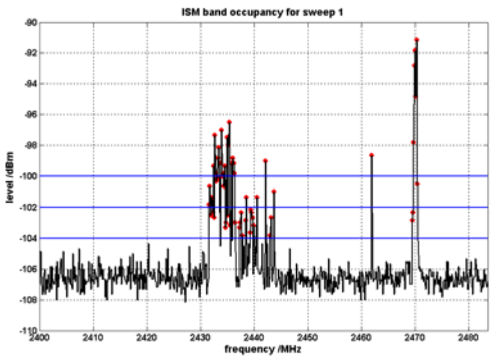


Sounder

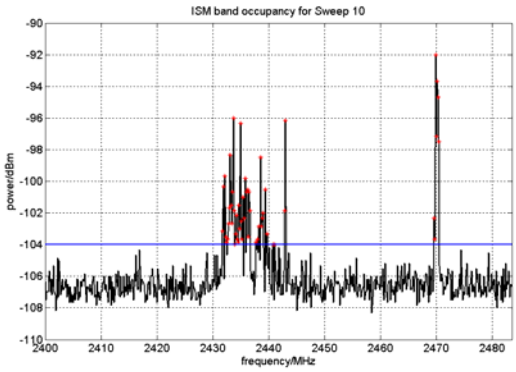


spectrum analyser

Figure 2 The resolutions of spectrum analyser and sounder.



(a)



(b)

Figure 3 Sweeps (a) 1 and (b) 10 of ISM band

Figure 4 displays the corresponding histogram of amplitude, indicated for threshold levels from–104 to –98 dBm in 2 dB steps. Figure 5 shows the scatter plot for –104 dBm threshold for the 15 sweeps. The mean occupancy equals 8.18% and the standard deviation is 0.0118. Apart from the frequency hopping of a bluetooth device the occupancy data exhibit stationary characteristic, which suggests that the spectrum occupancy is suitable for statistically modelling.

Until now, we just described some statistical information about the spectrum occupancy with graphics, which is often useful to make some simple characterization of the data. In future, the objective will be focused on modelling occupancy rate on communication parameters such as frequency, time and incident direction with generalized linear models.

4. Statistical Analysis of WiMAX Band

Measurements in the Isle of Wight were performed with the channel sounder using four receive channels simultaneously with four directional antennas with 90 degrees angular coverage.

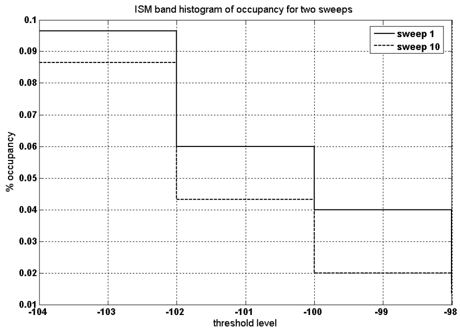


Figure 4. Some statistics for ISM band

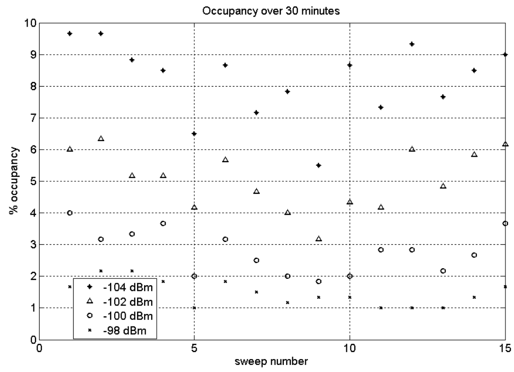


Figure 5. Occupancy for different threshold levels

5. REMARK

This paper presents spectrum analyser and sounder system as measurement equipments for spectrum occupancy and gives some simply statistics for 2.4 GHz ISM band's usage. The data suggest that long term observations are needed for accurate statistical modelling.

6. REFERENCE

[1] M. Biggs, A. Henley, "Occupancy analysis of 2.4 GHz ISM band," *IEE Proc. Commun*, Vol. 151, 481-488, 2004.

[2] S. Salous, N. Nikandrou, N. Bajj, "Digital techniques for mobile radio chirp sounders," *IEE Proc. Commun*, vol. 145, pp. 191-196, 1998.

[3] A. Gibson, L. Arnett, "Measurements and statistical modelling of spectrum occupancy," *IEE Sixth International HF Conference Publication*, 150-154, 1996.