Spectrum Occupancy Measurement and Analysis

Tian Fang [1], *Feng Zhiyong* [1], *Chen Xing* [2]
(1. Beijing University of Posts and Telecommunications, Beijing 100876, P. R. China;
2. Research Institution of China Mobile Communications Corporation, Beijing 100053, P. R. China)

Abstract:
This paper analyzes current spectrum utilization from all aspects based on related methods of spectrum measurement. The measurement results show that some spectrum resources are not used effectively due to current fixed spectrum allocation policy, and the spectrum occupancy varies dramatically in terms of time and space. These results provide basis for the development of next generation wireless communication technologies such as Cognitive Radio (CR).

With the rapid development of wireless communications, especially the significant increase of spectrum-based services and devices, more and more spectrum resources are in demand. At the same time, the spectrum resources are suffering great scarcity and almost all the low-frequency bands, which are of good propagation characteristics, have been allocated. With current spectrum management policy, which pre-allocates the spectrums for authorized users, some bands have heavy traffic on them, while the other bands are left idle most of the time, leading to huge waste of spectrum resources. From January 2004 to August 2005, the US Shared Spectrum Company conducted measurements on the utilization of the spectrum ranging from 30 to 3,000 MHz. The measurement results show that the average occupancy of these bands is only 5.2%[1].

The research and measurement of spectrum occupancy can reveal spectrum utilization. Moreover, the measurement results also provide basis for making spectrum allocation policies in the future, and help find out available bands for next generation wireless communication technologies, such as Cognitive Radio (CR), which could be used in heterogeneous networks.

Spectrum measurement requires simple, practical and efficient methods. During the spectrum measurement, it is important to set proper measurement parameters, make reasonable measurement scheme and accurately analyze the measurement results according to the characteristics of existing Radio Access Technologies (RATs) in each band. The analysis of measurement data will not only provide spectrum administrators with actual utilization of spectrums, enabling them to reasonably allocates spectrum, but also provide technical support for the concerned authorities to make CR management and spectrum allocation policies.

1 Measurement Scheme

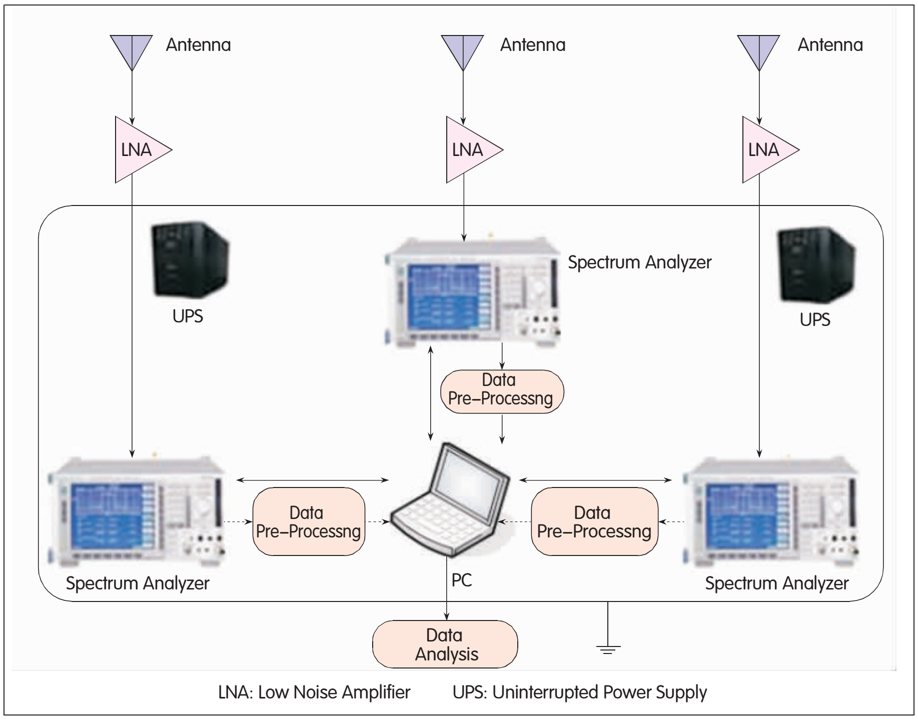
Before the spectrum measurement, a reasonable scheme should be seriously made based on specific purposes and objectives to determine such issues as measurement locations, measurement equipments and the spectrum bands to be measured[2-6]. A complete scheme can not only facilitate the quick deployment of spectrum measurement, but also has direct relation to the accuracy of the measurement results.

1.1 Selection of Measurement Location and Time

The spectrum utilization varies with scenarios. Therefore, the measurement work should be carried out in different scenarios respectively such as countryside, outskirts, urban areas, dense urban areas, and hotspots[2]. In each scenario, the locations selected for measurement should be typical enough to actually figure out the utilization of the spectrum in the measurement period. Meanwhile, the measurement periods differ from one scenario to another, due to the difference in radio environments. In general, for a specific band, which is usually involved in a small-scale measurement, the measurement time is often determined based on the measurement requirements; while a large-scale measurement requires long-time, continuous measurement because enough samples that cover several periods are needed in order to obtain measurement results that accurately reflect the spectrum occupancy of each period. As for the time of a large-scale measurement, the recommendation SM.1536 of International Telecommunication Union Radiocommunication Sector (ITU-R)[3] suggests seven consecutive days.

1.2 Selection and Setup of Measurement Equipment

In selecting measurement equipments, the specific communication technologies adopted in each band should be taken into account. For the bands where energy



▲Figure 1. Measurement equipment setup.

detection techniques can be directly used to detect and analyze the signals, common receivers or spectrum analyzers can meet the measurement requirements[4]; for some special bands, such as the bands for satellite communications, special measurement devices are required to receive and analyze the signals; while for CDMA systems, decoding devices are needed to conduct accurate measurement and analysis. Figure 1 illustrates a way to set up measurement equipment.

1.3 Setting Measurement Parameters

The measurement parameter settings are directly related to the accuracy of measurement result. Roughly, the important measurement parameters include revisit time[6], Resolution Bandwidth (RBW), Video Bandwidth (VBW) and decision threshold.

(1) Revisit Time

A proper revisit time should be set for spectrum occupancy measurement. If the time is set too long, those signals lasting for a short time may be missed, thus the reliability of the measurement result decreases. The recommendation ITU–R SM.1536 suggests a revisit time less than a half of signal transmission duration[3, 6].

In actual measurement, the setting of revisit time depends on the receiving device used. In case of a receiver, the revisit time could be determined by the measurement persons based on actual situations so as to increase the measurement precision. The revisit time should be set to a value smaller than the recommendation one but not too short; otherwise the sweep speed may exceed the responding speed of the device and leading to distortions in the measurement results. On the other hand, the signal characteristics are quite different among all communication systems, and the signal transmission duration in some bands is far less than revisit time. As a result, these signals are likely to be missed during measurement, bringing errors in the measurement results. When measuring the occupancies of such bands, enough samples should be collected so as to get accurate results from long–term statistics.

(2) RBW and VBW

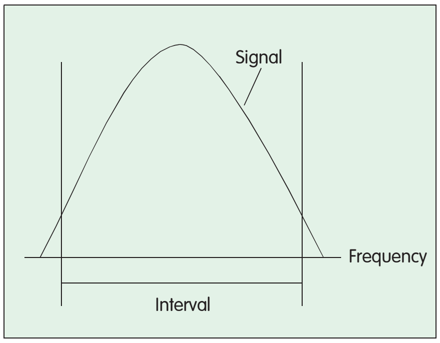
The size of RBW determines whether two neighboring signals could be separated, while VBW indicates the measurement precision. For example, if VBW is set to be 10 kHz, it means samples will be collected every 10 kHz for testing their levels.

To ensure the measurement result accurately reflects the occupancy of each system in a band, it is necessary, before each measurement, to learn the characteristics of services carried on the band, and then set RBW and VBW based on channel bandwidths of all communication systems. According to the occupancy situation of the frequency sampling points, it is easy to determine whether a channel is occupied. Often, the sampling interval should be less than half of the channel bandwidth. If the interval is too large, some signals may be missed and causes inaccurate measurement results. The impact of a large interval on the measurement results is shown in Figure 2. Experiments demonstrate that the higher the measurement precision, the more accurate the measurement result is.

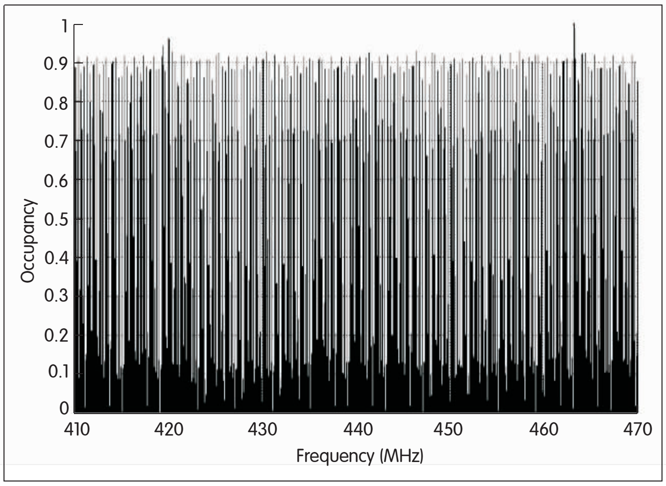
(3) Decision Threshold

As long as the sensitivity of the receiving system is ensured, the decision threshold level, which is used to distinguish the noise and signal, should be set as low as possible. In the case there are lots of small signals, a too high threshold is likely to miss these small signals, while a too low threshold may mistake some noises for the signal, leading to measurement errors[4].

A common method used to set the decision threshold is to add about 5 dB onto the average environmental noise. This method comes from past experience, which works quite well when noises do not change dramatically. The advantage of this setting method is that it allows noises and signals to be quickly distinguished, but it is too subjective and is not flexible enough to adapt to all measurement environments. If the noises fluctuate sharply, they are likely to be



▲Figure 2. Impact of large interval on the measurement results.



◀Figure 3. Spectrum occupancy measured with empirical threshold value.

incorrectly treated as signals, and the small signals may also be mistaken for noises, thus affecting the accuracy of measurement result. Figure 3 shows the spectrum occupancy measured with this empirical method. When the noises experience violent fluctuation, the measured occupancy will be much higher than the actual occupancy.

Frederick Weidling proposed a new method to determine the threshold for distinguishing signals from noises[7]. In this method, the noise variance is supposed to be a constant value, and the noise samples are gradually reduced using iterative approach until a constant noise variance is obtained, which will be used to determine the decision threshold. The advantage of this method is that the threshold is determined with a relatively objective method and it can be set for each channel. However, lots of experiments prove that this method is applicable to the cases where noises are more than signals and there is a significant difference between the noise power and signal power. In such cases, the measurement results are consistent with the actual ones. But when noise power are almost the same as signal power or the entire band is filled with either noises or signals, this method does not output satisfying measurement results. This is obviously a big defect of this method.

In the previous spectrum measurements in US, the threshold was determined by adding several dB to the noise peak[1]. This method can filter out most noises. As a result, the problem in empirical method is avoided: noises are treated as signals in case of violent fluctuation in noises, although some small signals may be treated as noises and filtered out, which leads to some errors in measurement results. In actual measurements, 3–5 dB are often added onto the noise peak to get the decision threshold. Figure 4 illustrates such threshold setting method.

This method is also empirical, but it can better separate noises from signals, thus achieving relatively reliable measurement results. In determining the threshold, in order to ensure small signals to be identified, the changes of occupancies when using different thresholds can be repeatedly compared and then the threshold as low as possible can be selected.

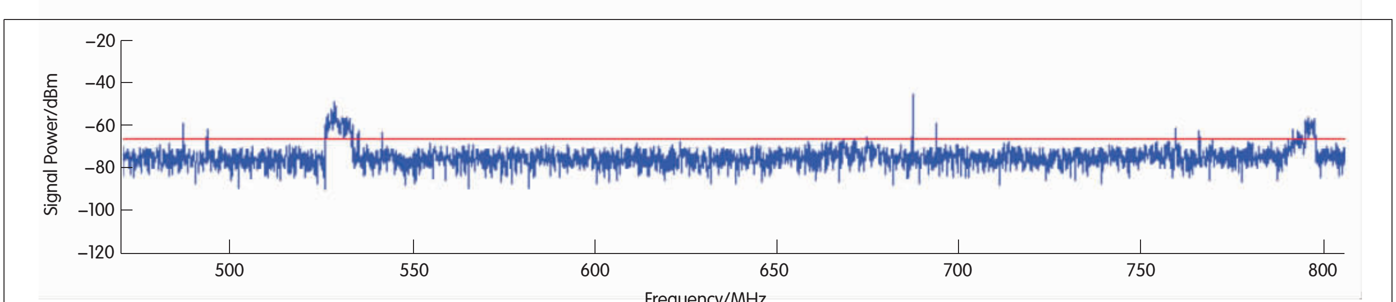
2 Analysis Methods of Spectrum Occupancy

In order to obtain the spectrum utilization of communication systems in each band, the analysis of measurement results should be conducted from several aspects, including power level and occupancy of the measured bands. For some dynamic spectrum allocation technologies that may be used in the future, more details about utilization of each band are necessary so as to get all–around knowledge of the change of spectrum occupancy. The section discusses several typical methods of analysis.

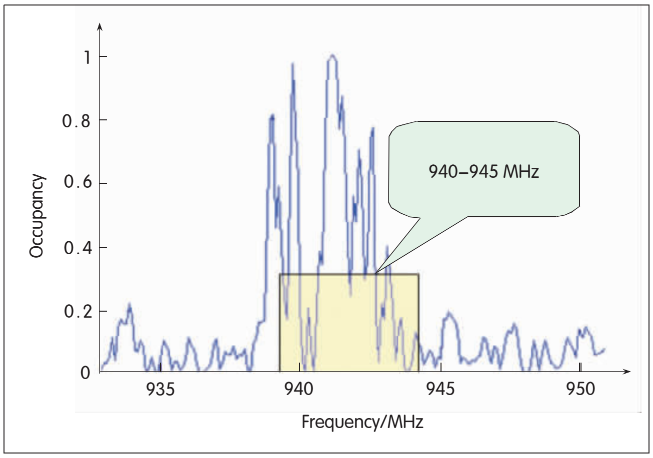
2.1 Frequency Occupancy

Normally, the measurement object is the channel occupancy. However, in a large–scale spectrum measurement, it is difficult to accurately measure the occupancy of each channel because a large number of bands are swept continuously and the channel characteristics in each band differ. Moreover, the large–scale measurement focuses on the overall occupancy of a band rather than the occupancy of specific channel. We could obtain the occupancy of measurement bands through analyzing and calculating the occupancy situation of all frequency sampling points. Here the frequency occupancy is used to analyze the occupancy of each frequency sampling point. The calculation is as follows:

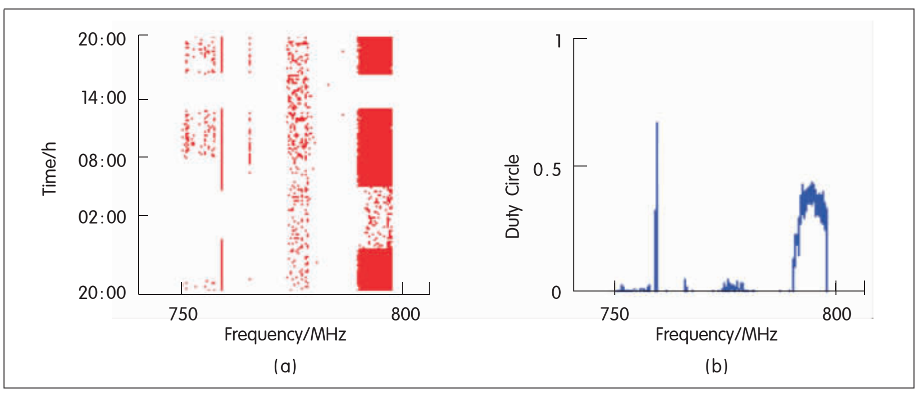
Occupancy is a statistic value or an estimated value. In a continuous measurement period of a frequency sampling point, it is the percentage of the time when the signal power exceeds the



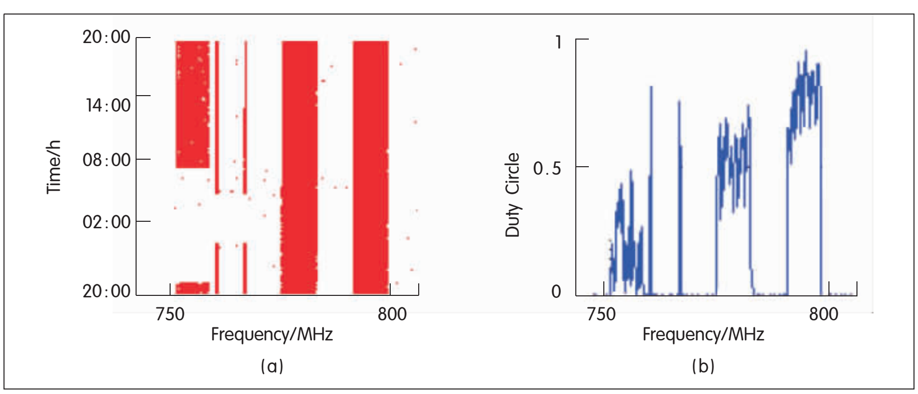
▲Figure 4. Decision threshold setting method used in the spectrum measurement.



◀ Figure 5. Spectrum band occupancy.



▲ Figure 6. Spectrum occupancy of 750–800 MHz in a hotspot area.



▲ Figure 7. Spectrum occupancy of 750–800 MHz in a dense urban area.

threshold accounting for the total measurement time[6], which could be expressed as:

$$\eta = (T_1 / T_2)\times 100\% \quad (1)$$

where η is the occupancy, T_1 is the sum of the time when the signal level exceeds the threshold, and T_2 is the total measurement time.

2.2 Spectrum Band Occupancy

The spectrum band occupancy could be obtained by calculating the occupancies of all frequency sampling points in this band. It is the average occupancy of all frequency points of the band within a certain period. For example, suppose there are 100 frequency sampling points in a band for measurement and the occupancies of the 100 points are measured, which are normally not the same. To compute the overall occupancy of this band, the occupancies of the 100 frequency points are first summed up, and then the sum is divided by 100. This average occupancy is regarded as the occupancy of the entire band. Figure 5 illustrates the spectrum band occupancy.

The analysis of spectrum band occupancy is helpful for understanding the utilization of the band within a period. By comparing the occupancies of all bands, we can learn their utilization, thus finding out the bands available for CR or other new technologies.

3 Analysis of Measurement Result

The analysis of measurement results should reflect the difference of spectrum occupancy in terms of time, location and frequency. Figure 6 shows the measurement results of the occupancies in hotspot areas of 750–800 MHz, which is allocated to transmit television signal, Figure 6(a) is the occupancy situation of each frequency sampling point in 24 hours of a day. Figure 6(b), corresponding to Figure 6(a), is the one day's overall occupancy of each frequency sampling point. The more time a frequency is occupied in Figure 6(a), the higher the overall occupancy is in Figure 6(b). As shown in the figure, the entire band is not fully used in the measurement period. Some spectrums are occupied for quite a short time or even not occupied at all. This suggests the difference of spectrum occupancy in time and frequency.

Figure 7 shows the occupancies of the same band (i.e. 750–800 MHz) in dense urban areas. Compared with Figure 6, the spectrum occupancies in dense urban areas are much higher, which indicates that the occupancies of this band vary with different scenarios. According to the occupancy measurements of the abovementioned band (750–800 MHz) in different locations, the occupancy value in hotspot areas is 0.0818 and that in dense urban areas is 0.2311. The latter is much higher than the former but is still at a low level.

Figure 8 illustrates the distribution of occupancies of 750–800 MHz, which depicts the occupancies of all frequency sampling points of this band by hours. Compared with Figures 6 and 7, Figure 8 is more comprehensive, where not only whether a band is occupied in a certain period is seen, but also the occupancy of

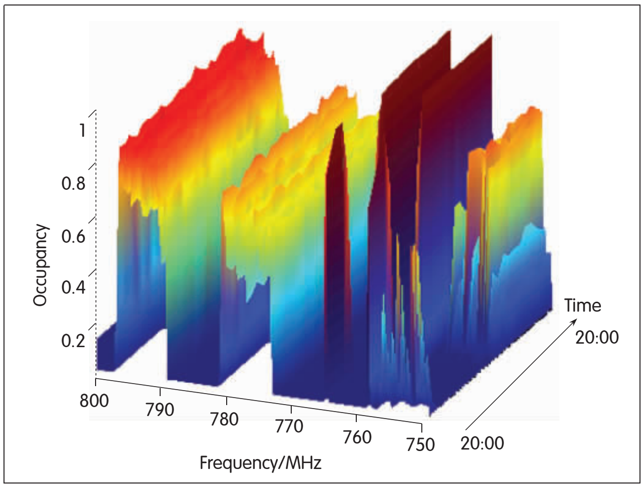


Figure 8.
Change in occupancies of 750–800 MHz (dense urban areas in China).

this band in the period. These figures also show that although lots of spectrum resources have been allocated, only a small part of them are well used. Some bands are not used almost all the time, and some are highly occupied in daytime but are not used in the night. This surely decreases the overall utilization of the measurement bands. On the whole, the occupancies of most spectrum resources in this band still stay at a very low level.

4 Conclusions

The occupancy measurements of current allocated spectrums can not only provide a convincing basis for making future spectrum allocation policies, but also provide technical support for the development of new communication technologies. This paper suggests some measurement and analysis methods based on the achievements and experience that have been obtained from current measurements, which can be used as references for future measurements. The measurement results show that some frequency bands are not effectively used and hugely wasted, while other bands are always highly occupied and their spectrum resources are increasingly wanted. However, with current fixed spectrum allocation policy, it is difficult to find out new spectrum resources to alleviate the spectrum shortage problem. Therefore, new spectrum utilization technologies, such as DSA, have to be developed to effectively solve such problem in the future. This requires more detailed measurement and analysis of current spectrums so as to find the bands that are suitable for carrying these new technologies.

References

[1] MCHENRY M A, MCCLOSKEY D. New York City spectrum occupancy measurements September 2004 [EB/OL]. Shared Spectrum Company. http://www.sharedspectrum.com. 2004.
[2] ITU-R M.1645. Framework and Overall Objectives of the Future Development of IMT2000 and Systems Beyond IMT2000 [S]. 2003.
[3] ITU-R SM 1536. Frequency Channel Occupancy Measurements [S]. 2001.
[4] Evaluation of spectrum occupancy in indoor and outdoor scenario in the context of cognitive radio [C]// Proceedings of 2nd International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom'07), Aug 1–3, 2007, Orlando, FL, USA, 2007: 420–427.
[5] **中华人民共和国无线电频率划分规定**[EB/OL]. 2006-09-05. http://rf.beijing2008.cn/upload/dc/1-Allocations_CN.pdf.
[6] **段洪涛. 频谱占用度测量及相关参数确定** [J]. **中国无线电**, 2007(3): 6–15.
[7] WEIDLING F, DATLA D, PETTY V, et al. A framework for RF spectrum measurements and analysis [C]// Proceedings of 1st IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN'05), Nov 8–11, 2005, Baltimore, MD,USA. Piscataway, NJ, USA:IEEE, 2005: 573–576.

Biographies

Tian Fang

Tian Fang is a master's degree candidate, majoring in telecommunication and information systems at Beijing University of Posts and Telecommunications (BUPT). Her research direction is new technologies for broadband mobile communications.

Feng Zhiyong

Feng Zhiyong is an associate professor in the Wireless Technology Innovation Institute of BUPT. She is mainly engaged in the research of cognitive wireless networks.

Chen Xing

Chen Xing, PhD, is a project manager at the Wireless Technology Research Lab of the Research Institution of China Mobile. She is mainly engaged in the research of technologies related to LTE-Advanced and cognitive radio.

Roundup

ZTE SDR Base Station Records over 100,000 Volume Shipment

ZTE Corporation announced on May 26, 2009 that its Soft Defined Radio (SDR) base station had recorded a total volume shipment of 107,000 units since its latest product advancement in October 2008.

In October 2008, ZTE's SDR products won an InfoVision award at Broadband World Forum (BBWF) Europe 2008 from International Electrotechnical Commission (IEC), reinforcing ZTE's position as a market leader in network innovation. In February 2009 at the World Mobile Congress in Barcelona, ZTE's SDR solution was also nominated for GSMA's 14th Global Mobile Awards, representing the only nomination for a Chinese company.

ZTE earlier this year partnered with CSL Hong Kong to launch the world's first SDR-based HSPA+ commercial network, considered the world's fastest 3G commercial network ever developed.

(ZTE Corporation)