Beijing Spectrum Survey for Cognitive Radio Applications

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***Abstract*—In order to investigate the status of the radio spectrum usage with different services in Beijing, we have conducted a 24-hour spectrum measurement and spectrum usage pattern analysis in May 2012 in the frequency bands ranging from 440 MHz to 2700 MHz. Based on the measurement results, we try to identify the suitable bands for new spectrum access technologies such as cognitive radio which can improve the efficiency of spectrum usage. The results from the spectrum measurements taken over a two weekday period reveal that a significant amount of spectrum has a very low occupancy over the time. On average, the actual spectrum usage in all bands is about 15.2%. The observed low spectrum occupancy in the business center in Beijing indicates that there is a great potential for employing the dynamic spectrum access technology such as the cognitive radio to accommodate enormous demands for future wireless services and improve the vacant spectrum usage.**

***Index Terms*—Spectrum measurement, Cognitive Radio Networks, Dynamic Spectrum Access**

I. Introduction

Radio spectrum resources play fundamental important roles in the wireless communication systems. The rapid growing demand for wireless communication services and the inefficient spectrum allocation methods result in the scarcity of the spectrum resources, which greatly hinders the development of future wireless communication systems[1][2].

For example, in China, the State Radio Regulatory Commission of China (SRRC) divides the whole available magnetic spectrum resources into many frequency sections, and assigns them for different license services such as broadcast TV, cellular networks for exclusive use. Such fixed spectrum allocation approach ensures that wireless applications and devices don't cause any harmful interferences with each other. However, it results in the inefficient use of the current radio spectrum. Some bands heavily occupied by busy radio services while other bands are seldom used at all. There are already great difficulties to find unassigned spectrum for the new broadband wireless communication services such as Time Division Long Term Evolution(TD-LTE).

One of the most promising solutions to overcome this problem is the cognitive radio technology(CR). A CR device has the ability to identify an unoccupied spectrum band for temporarily usage, and vacate the spectrum when it is necessary. Therefore, CR is viewed as a technology to overcome the current inefficient usage of radio spectrum resources[3][4].

Due to its importance, a lot of research funds have been invested to develop cognitive radio technology. National research programs have already been founded to support CR technology in China such as 973,863 Program and National Science Funding project. Government policy regulators such as SRRC are considering modifying current spectrum allocation polices in order to enabling dynamic spectrum access technologies. However, if they fail to fully understand the current spectrum occupancy patterns, all these investments and efforts may not produce the expected results.

Spectrum occupancy survey is one of the essential tools for spectrum management which provides the policy makers with the necessary information about the frequency usage pattern of different services in different frequency bands. Till now, several measurement campaigns have already been conducted in USA, Singapore,Vietnam, and Germany, [5][6][7][8]. All these studies show a common finding that a large portion of the assigned spectrum resources are seldom used at all while some particular spectrum bands are overcrowded. In this paper, we report the detail measurement results of a two week period radio spectrum measurement survey of 440 MHz to 2700 MHz in Beijing.The goals for this measurement are not only to fill the gap of current lack of knowledge about the radio spectrum usage pattern in Beijing China, but also to find out the frequency bands which are suitable for future dynamic spectrum access products such as CR devices.

The rest of this paper is organized as follows. We introduce the measurement setup and procedure details in section II. The methodology for data analysis is described in section III. Section IV presents the measurement results and discussions. Finally, the conclusion of the whole paper is given at the section V.

II. Measurement setup and procedure

The 24-hour spectrum measurements were conducted in June 2012 Beijing, at an outdoor environment on the rooftop of a 30 storey(115 meters high) building near the central business district (CBD), which is located at No.1 Fuwaidajia Rd. Xicheng District of Beijing, China,with a coordinate 116.3483912175941° and 39.92310002818954°.

There are no higher buildings surround the measurement site, which enables us to accurately measure all the radio spectrum activity nearby.

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As shown in Figure 1, the equipments used for measurement in this study consisted of an omni-directional BOGER DA-5000 broadband antenna with frequency range from 70MHz-3GHz as shown in Figure 2.The antenna was connected to a Agilent N9030A Spectrum Analyzer,which has a operating frequency range of 3 Hz to 3.6 GHz, measurement range from -154 dBm to 30 dBm.A laptop computer was used to control the spectrum analyzer.An uninterruptible power supply(UPS) was used to maintain reliable power supply.All the equipments except of antenna were placed to a shielded enclosure cage as shown in Figure 3.

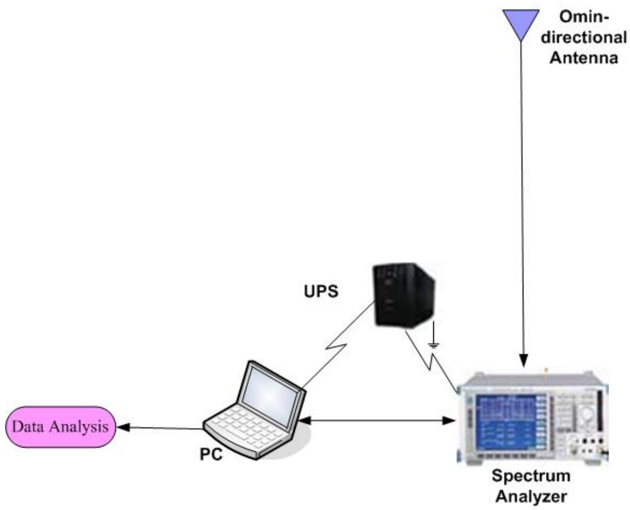

Fig. 1. The connection and deployment of measurement equipments

Fig. 2. BOGER DA-5000 broadband antenna

The overall measurement frequency band which is from 47 MHz to 5000 MHz is divided into several frequency bands according to its authorized services for more accuracy measurement.The Spectrum Analyzer was configured with the resolution bandwidth(RBW) varying between 15 kHz, 100 kHz, and 200 kHz depending on the actual bandwidth of the allocated signal.

Fig. 3. Equipments in a shielded enclosure cage

The measurement for each frequency band is carried out around approximately every 2.23s. In total, nearly 241 million samples were taken during 2 week period spectrum occupancy measurement.

III. METHODOLOGY FOR DATA ANALYSIS

Spectrum occupancy rate is the most used metric to measure the utilization of spectrum.It is generally defined as the probability of the event that the measured signal strength of a certain frequency bandwidth is above a certain threshold[5][6][7]

Selecting the threshold too low would result in a higher spectrum occupancy estimation since the presence of noise may be wrongly considered as the signal. On the other hand, if the threshold is chosen too high, some channels may be considered as unoccupied even though there may be some authorized services operating at low power. According to the existing literatures on spectrum survey[6][7][8][9][10],a 5dB threshold above the noise floor is considered as the final threshold value.

The raw data represents the received signal power level measured at the spectrum analyzer, and need to be calibrated to the power level at the antenna input for precise measurement.Therefore, the difference values between the power level at the spectrum analyzer input and the power level at the antenna versus frequency were recorded. Then ,the calibration values from spectrum analyzer are added to these difference values when plotting the spectrum data in this report.

IV. SPECTRUM OCCUPANCY PLOTS AND OBSERVATIONS

In this section, we present spectrum occupancy results in different frequency bands one by one.

Each of the spectrum occupancy plots consists of three subplots. The upper sub-plot depicts the received power at the antenna input versus frequency during a single measurement, which is used to show the waveform of the occupied signal as well as to verify that the threshold (the red line) is properly selected. The middle sub-plot is a waterfall-type plot with spectrum occupancy versus time and frequency. Occupancy is determined when the received power level at the antenna exceeds the threshold. The lower sub-plot shows the duty cycle versus frequency, where the duty cycle is defined as the fraction of time the received signal power of a single frequency is above the threshold. Therefore, the average spectrum occupancy rate of the whole frequency band is calculated as:

$$average \quad spectrum \quad occupancy = No/N$$

where No is the total number of the received samples with received power exceeding the threshold for the whole 2 week period and N is the total number of received samples in the whole frequency band during the whole 2 week period.

Figure 4 shows the spectrum occupancy from 440 MHz to 470 MHz measured in Beijing during a 24-hour period from 17:00 , 8 May 2012 to the following day. This frequency band is authorized as radio navigation, radio location and land mobile services such as talkie and walkie devices. The average spectrum occupancy is observed as 0.076. The relative low spectrum occupancy results in that the temporary used of the frequency is usually very short.

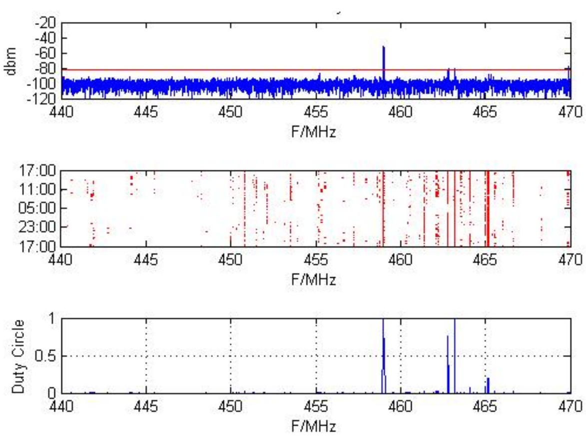

Fig. 4. Fixed/Radiolocation/Land Mobile 440 MHz-470 MHz

Next, we show the spectrum occupancy in the bands 470 MHz to 806 MHz in Figure 5. This band is allocated to the broadcasting (analogue TV PAL-DK, digital TV DTMB) services. The average spectrum occupancy is about 0.31. As we can see, not all of the TV stations work 24 hours a day. Many TV channels closed from 23:50 to 5:50. And there are many unused TV frequency channel exists.

Figure 6 shows the spectrum usage of 840 MHz to 890 MHz band allocated for digital cellular services(CDMA 800 MHz), trunked radio services and mobile data services. The average spectrum occupancy of this band is 28.68%.Note that the between the spectrum occupancy of uplink and downlink sides of CDMA 800 MHz are not identical. Similar occupancy pattern has been observed in the uplink and downlink bands of GSM service as can be seen in Figure 7. The average spectrum occupancy of GSM service is about 40.2%. The different patterns of uplink and downlink of cellular networks

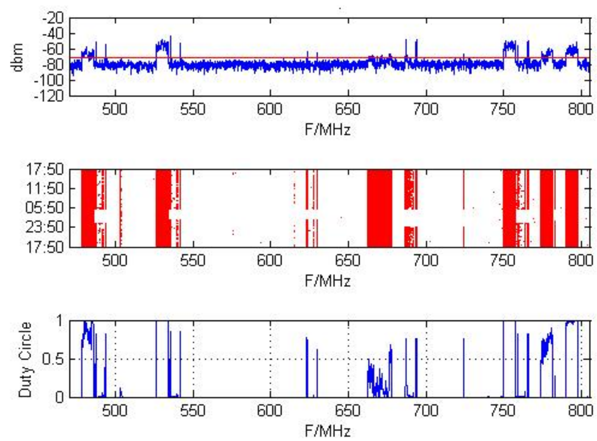

Fig. 5. Broadcasting TV 470 MHz-806 MHz

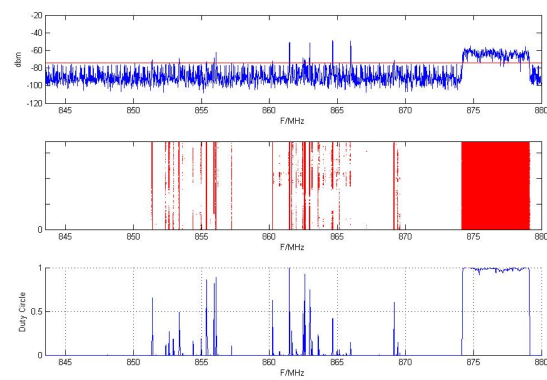

Fig. 6. CDMA bands 840 MHz-880 MHz

can be explained as following. The base stations are constantly broadcasting control channels on the downlink, with larger transmitting power compared to the mobile terminal, resulting in the nearly fully spectrum occupied patterns. The transmitting power of uplink for cellular systems is relative low then the downlink, and hardly to be detected if there is no active communication.

Figure 8 shows the spectrum usage by IMT-2000 TDD band (2300 MHz to 2400MHz). This band is assigned as the candidate band for TD-LTE and TD-SCDMA. It appears that the whole band of 2300 MHz to 2400 MHz is completely unused during 2 week observation.

Figure 9 shows the spectrum usage by Industrial, Scientific and Medical (ISM) band (2400 MHz to 2500 MHz). It appears that the whole band of 2400 MHz to 2500 MHz is completely unused during 2 week observation. Similar occupancy pattern has been observed in the marine time/radar/multichannel multi-point distribution services(MMDS) frequency band from 2500 MHz to 2700 MHz (Figure 10), where only a MMDS signal was captured in 2541 MHz. The occupancy estimates of these bands might not be the representatives of the actual occupancy

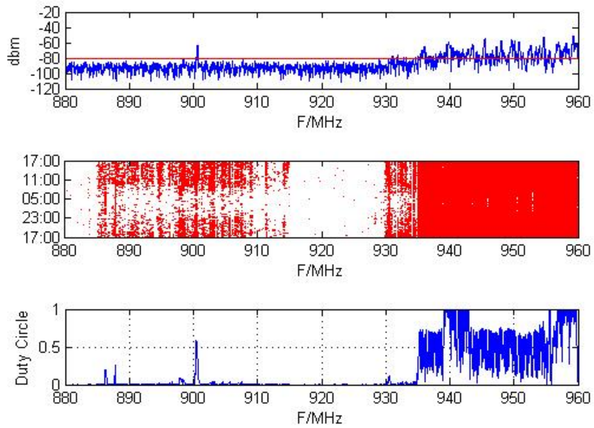

Fig. 7. GSM bands 880 MHz-960 MHz

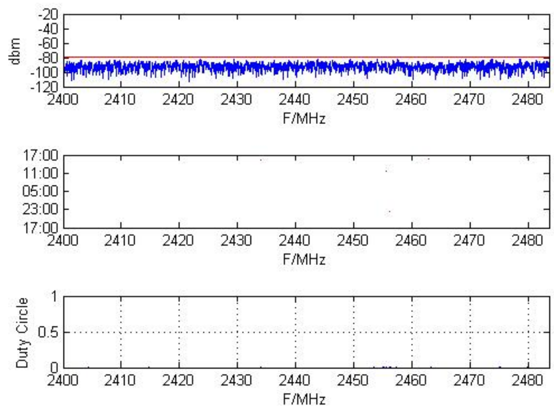

Fig. 9. ISM band 2400 MHz-2500 MHz

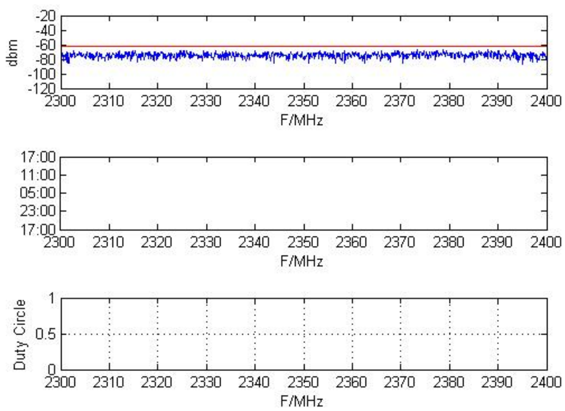

Fig. 8. IMT-2000 TDD band 2300 MHz-2400 MHz

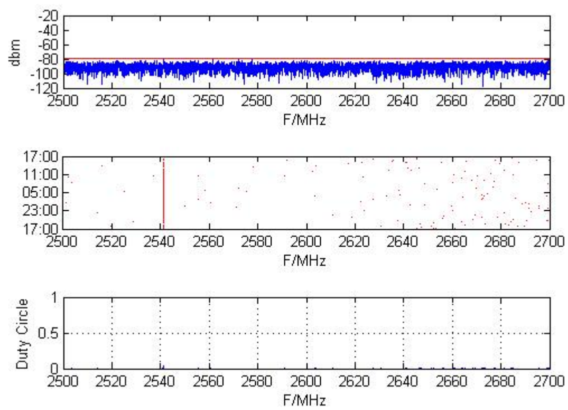

Fig. 10. Marine time/Radar band/MMDS 2500 MHz-2700 MHz

such as WLAN, Bluetooth. Since all these services are mostly short range transmission and the measurement site is on the rooftop of a 30 storey(115 meters high) building,the transmitters of the ISM signals may not be closed enough to be detected. Furthermore, ISM signals may not penetrate through heavy walls. Radar signal may need special detection methods and equipments since its pulse is too short to be detected for common frequency sweep mode receivers, resulting in a low probability to be captured But still, several measurement points are strongly exceeding the threshold as can be seen in the Figure 10 waterfall plot. But due to there short temporary occupancy rate, the average spectrum occupancy is nearly zero. However, if we can confirm this points are truly radar signals, then the spectrum occupancy may increase dramatically, since frequency occupied by radar signal can not be used even if radar signals only occupied in small fracture of time due to the regulations and mechanisms of radar system. Otherwise, radar may be jammed.

To this end, we show the average spectrum occupancy rate in Beijing City band-by-band in Figure 11. The results of these measurements indicate that some spectrum bands are subjected to exhaustive usage while some others are sparsely used or show temperate utilization, and, in some cases, are not used at all. In general, the average spectrum occupancy observed in Beijing is 15.2% for the whole frequency range between 440 MHz and 2700 MHz. That means that 84.8% of this completely allocated spectrum was unused.

V. Conclusion

The spectrum measurements presented here are part of a larger on-going measurement campaign conducted by Beijing University of posts and telecommunications in several cities in the north of China. The purpose of this project is to capture enough useful data in order to create a radio spectrum information database to guide the cognitive radio applications for high efficient dynamic spectrum access in China. The challenge of this campaign is not only cost of the equipment but also time for measurement and mass data analysis in order to obtain the

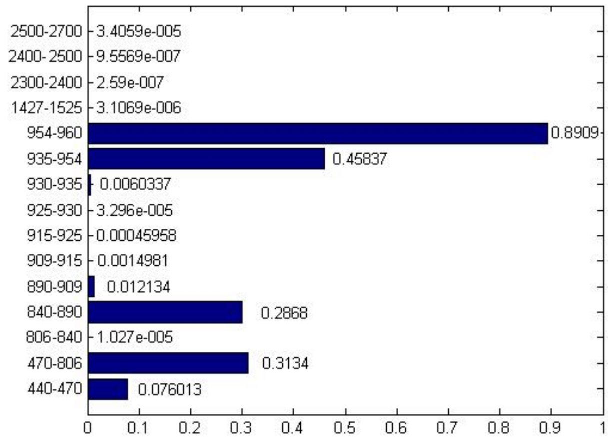

Fig. 11. Summary of spectrum occupancy of Beijing

accurate radio spectrum usage pattern. Our measurement results show that most of already allocated frequency bands have low spectrum occupancy rates, except for TV broadcast services and mobile cellular networks bands. CR applications can be easily realized by exploiting bands with low measured radio spectrum occupancy rates. Measurement data will further guide to design highly efficient spectrum sensing algorithms and other dynamic spectrum access mechanisms which fit the characters of radio environments for the future work.

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