Measurement and Analysis of Wideband Spectrum Utilization in Indoor and Outdoor Environments

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***Abstract*—Spectrum awareness is an essential part of Cognitive Radio (CR) systems that enables CR systems to intelligently utilise the spectrum. Accurate modeling of spectrum utilization is crucial for the development and performance evaluation of such systems. In this paper, a wideband spectrum occupancy measurement campaign is conducted to study the utilization of RF spectrum in indoor and outdoor environments simultaneously. The measurements are performed in the 700-3000 MHz frequency band over three consecutive days at an indoor and an outdoor location concurrently. The measurement results show that spectrum utilization in indoor and outdoor environments is significantly different and these differences are quantified. The measurement results suggest the integration of location information to the dynamic spectrum access methods.**

Keywords- cognitive radio, spectrum occupancy, measurement, indoor, outdoor environments.

I. Introduction

Efficient spectrum utilization is becoming more crucial as new wireless technologies and services demand more spectral resources, which are scarce in nature. One of the most promising technologies for efficient spectrum utilization is Cognitive Radio (CR) (Mitola et. al., 1999) of which, spectrum awareness is a prominent feature (Quan et. al., 2008). Empirical modelling of spectrum occupancy is crucial for the development of efficient dynamic spectrum access techniques since it is not possible to estimate the spectrum occupancy accurately (even for licensed bands) because of the dynamic nature of its utilization.

Some spectrum occupancy measurement campaigns have been conducted in the United States, Europe and Asia (Islam et. al., 2008), (Wellens et. al., 2007), (Erpek et. al., 2007), (McHenry et. al., 2006), (Chiang et. al., 2007), (Ellingson, 2005), (Petrin et. al., 2005), (Do et. al., 2004), (Sanders, 1998). The majority of these studies can be categorized as single band monitoring, time - frequency analysis, and indoor vs. outdoor measurements. For instance, the spectrum occupancy over time and frequency is studied in (Erpek et. al., 2007) and (McHenry et. al., 2006) while (Wellens et. al., 2007) studies the spectrum occupancy for indoor vs. Outdoor considering time and frequency domains without synchronization between measurements. One of the common conclusions of the previous measurement campaigns is that spectrum occupancy highly depends on the location (e.g. country at high level). In addition, the previous studies did not take into account the practical considerations such as practical threshold level that cognitive radio devices can use, synchronization between the measurements at different locations, and rapid and low complexity multiband spectrum sensing. Therefore, we performed a wideband multidimensional spectrum occupance study by taking the practical considerations into account in the City of Doha in the State of Qatar. The first set of results of this measurement campaign is published in (Qaraqe et. al., 2009) where we report the results for wideband multidimensional spectrum usage over three consecutive days considering $700-3000$MHz spectrum at four outdoor locations concurrently. The current paper is an extension of (Qaraqe et. al., 2009) where we perform a wideband RF spectrum measurement campaign over the $700-3000$MHz band in order to evaluate the variations of spectrum utilization in an indoor vs. an outdoor environment concurrently in the State of Qatar.

The remainder of the paper is organized as follows; the measurement setup and procedure are presented in Section II. This is followed by presenting and discussing the measurement results in Section III. Finally, the conclusions are presented in Section IV.

II. Measurement Setup and Procedure

A. Measurement Setup

The measurement setup and settings used are identical for both the indoor and the outdoor locations and the measurement setups at both locations are shown in Figs. 1 and 2, respectively.

In the setup, a Rohde & Schwarz FSH6 Portable Spectrum Analyzer (SA) is connected to a laptop via a USB-optical cable. The SA is also connected to a very high performance discone antenna (AOR DA5000) with a 700-3000 MHz frequency range and omni-directional horizontal receive capability. Table I shows the settings of the SA, which is configured to measure the received signal power and store into laptop in real-time.

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Fig. 1. Measurement setup in indoor location.

Fig. 2. Measurement setup in outdoor location.

A sweep time of 128msec is selected as an optimum period considering the rise and fall times of sweeping band-pass filter and frequency resolution requirements. However, the rate of data collection is set to 1 reading per minute, where the entire spectrum of the 700-3000MHz band is swept at once with this sweep-and-dump rate. This was done for three consecutive days spanning both weekdays and weekend day [1] which covers high as well as low population activity that can be reflected in spectrum utilization. Note that the selected frequency range is an active part of the spectrum where most of the current wireless communications systems are deployed.

TABLE I
SPECTRUM ANALYZER SETTINGS

Center Frequency	1.85 GHz
Frequency Span	2.3 GHz
Resolution Bandwidth	300 kHz
Video Bandwidth	300 kHz
Sweep Time	128 ms

Several software packages are used throughout the study. The Rohde &S chwarz FSHview is used to save the measurement data obtained by the SA in the laptop. Furthermore, MATLAB is used for data post-processing and analysis.

B. Measurement Procedure and Data Post-processing

The measurements are conducted in Education City which is located in the west of the city of Doha and comprises a number of education campuses surrounded by vast open and generally flat spaces with some construction work going on in the campus and its immediate surroundings. There are not commercial and residential buildings or areas in the vicinity. In this area, the measurement data is collected in the Texas A&M University at Qatar (TAMUQ) Engineering building. The roof of TAMUQ Engineering building is selected to be the location for representing outdoor environments and is denoted Education City-outdoor in this study. The wireless teaching laboratory at the second floor of the same building is chosen to be location for representing the indoor environments and is denoted Education City-indoor. The measurement is performed between March 24, 2009 at 6.00PM Qatar local time and March 27, 2009 at 6.00PM Qatar local time at the two aforementioned locations synchronously. Note that the clock of each measurement setup is synchronized prior to placing them in their respective measurement locations. In addition, the measurement at both locations are started and stopped synchronously. As a result, 4320 different readings of the $700 - 3000$MHz spectrum are collected for each location.

The average power spectral density (PSD) curves are obtained by averaging all the readings that are collected during the three-day measurement period for each of the locations and the results are superimposed. The utilized (occupied) bandwidth percentage in $700 - 3000$MHz spectrum over the three-day measurement period is calculated for each spectrum reading as follows; first, a threshold level is set in order to determine the utilized bandwidth. We measure the thermal noise of the measurement system, which is found to be -78dBm over $700 - 3000$MHz spectrum. However, a margin of 3dB is considered for determining the final threshold value in order to account any unforeseen effects and variations (Wellens, 2007). As a result, -75dBm is used as threshold throughout this study. If the measured PSD in a certain frequency is above this threshold, then this band is reported as utilized band otherwise it is considered as idle. In the following sections, the measurement results for each location are presented and discussed.

[1] The official weekend days in the State of Qatar are Friday and Saturday. In addition, the afternoon term is loosely used in this paper and it is mainly for 1:00PM-4:00PM time slot. Note that this time slot is a common but unofficial mid-day break in the State of Qatar due to extreme weather conditions such as high temperature and humidity.

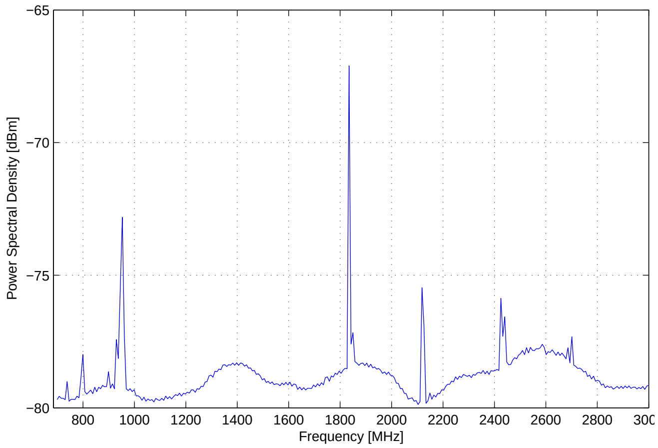

Fig. 3. Average power spectral density vs frequency at Education City-indoor location from March 24, 2009 6.00PM to March 27, 2009 6.00PM.

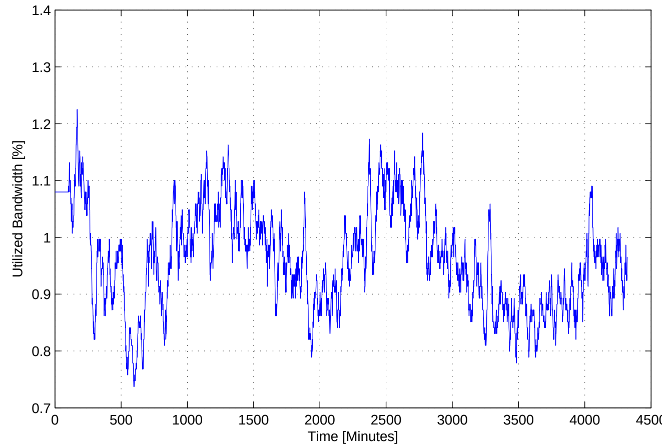

Fig. 4. Utilized bandwidth vs time at Education City-indoor location from March 24, 2009 6.00PM to March 27, 2009 6.00PM.

III. Measurement Results and Discussion

The average PSD over the frequency for the indoor location is shown in Fig. 3. According to the results, the only observed strong channels are in the 950MHz and 1800MHz bands corresponding to the downlink (base station to mobile station) transmissions of GSM900 and 1800 and are due to the indoor solution in place by one of the operators. In addition, weak signals of TV broadcasting around 800MHz, 3G/UMTS around 2100MHz, and Wi-Fi in 2400MHz are identified in this location. Fig. 4 shows the utilized bandwidth over the three days for this location. The bandwdith utilization varies around the mean value of 1% with a standard deviation of 0.2. Finally, Fig. 5 shows the 3D plot of PSD over time and frequency for this location.

Average PSD over the frequency spectrum for the outdoor location is shown in Fig. 6. The TV broadcasting channels are observed in the band around 800MHz. In addition, strong GSM channels are clearly identified in 950MHz and 1800MHz bands. In the bands around 2100MHz, 3G/UMTS channels are observed. Moreover, Wi-Fi channels with weak signal strength are observed at 2400 MHz band. Finally, WiMAX channels are clearly identified in $2470 - 2720$MHz band. Fig. 7 shows the utilized bandwidth over three consecutive days in the outdoor location. It is observed that the bandwidth utilization in the outdoor environment has the mean value of 15.3% with a standard deviation of 0.5. The 3D plot of PSD over the three days and the frequency spectrum is shown in Fig. 8. As a result, the spectrum occupancy in the case of indoor measurements lower than that in outdoor case because signals are attenuated considerably compared to the outdoor case.

IV. Conclusions

A wideband spectrum occupancy measurement is performed in indoor and outdoor environments concurrently in order to compare and quantify the spectrum usage in indoor and outdoor environments in the State of Qatar. Both types of environments differ from each other in terms of spectrum utilization.

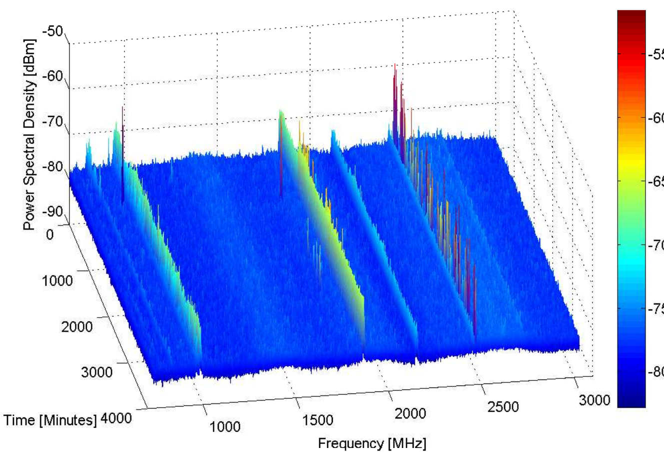

Fig. 5. Power spectral density vs time vs frequency at Education City-indoor location from March 24, 2009 6.00PM to March 27, 2009 6.00PM.

The results are quite interesting considering the two receivers where located at more or less the same coordinates, yet their reading differed significantly. For example, we observed TV and WiMAX signals are much weaker in the indoor environment. This is largely due to the huge penetration loss associated with the type of building in Qatar, which generally speaking, uses reinforced concrete. This means that CR systems have to be able to distinguish the type of environment they are in as a slight transition from one to the other can cause some degree of interference.

Bandwidth utilization is also different for both type of environment and this difference is quantified. In the indoor environment, the bandwdith utilization varies around the mean value of 1% with the standard deviation of 0.2. On the other hand, the bandwidth utilization in the outdoor environment

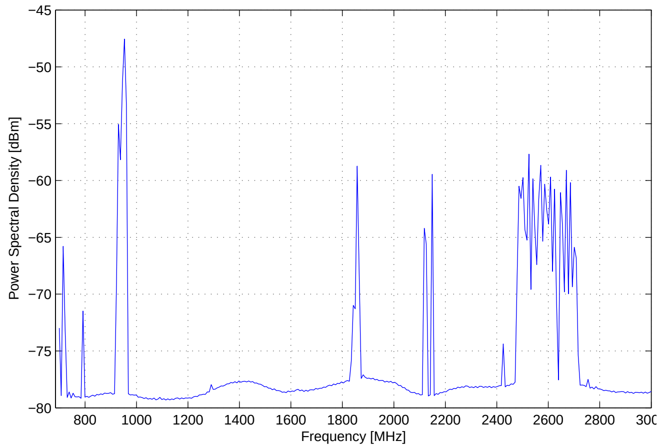

Fig. 6. Average power spectral density vs frequency at Education City-outdoor location from March 24, 2009 6.00PM to March 27, 2009 6.00PM.

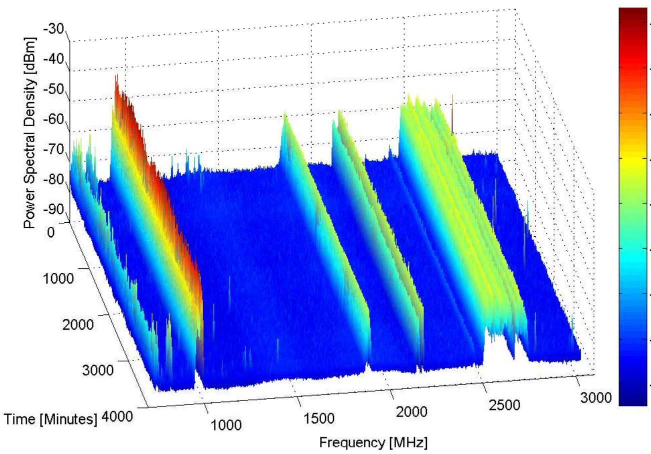

Fig. 8. Power spectral density vs time vs frequency at Education City-outdoor location from March 24, 2009 6.00PM to March 27, 2009 6.00PM.

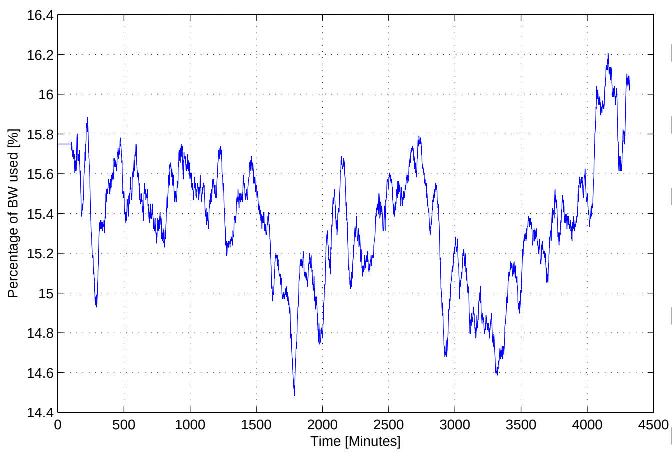

Fig. 7. Utilized bandwidth vs time at Education City-outdoor location from March 24, 2009 6.00PM to March 27, 2009 6.00PM.

fluctuates around the mean value of 15.3% with the standard deviation of 0.5. It is obvious from the measurement results that spectrum occupancy highly depends on the location. Therefore, we highly recommend to integrate location information to efficient spectrum utilization methods. Novel ideas can be established from this study and that in (Qaraqe et. al., 2009). For example, cooperative relaying can be utilised to exchange information about spectrum utilization and this could help further optimise CR systems.

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