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Patil, Kishor P.; Barge, Snehal; Skouby, Knud Erik; Prasad, Ramjee

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Evaluation of Spectrum Usage for GSM band in Indoor and Outdoor Scenario for Dynamic Spectrum Access

Kishor Patil[1], Snehal Barge[2], Knud Skouby[3], Ramjee Prasad[4]
Center for TeleInFrastruktur (CTIF), Aalborg University, Aalborg, Denmark[1, 4]
E-mail: {kpp, prasad}@es.aau.dk[1, 4]
Sinhgad Academy of Engineering, Pune, India[2]
E-mail: snehal.barge6@gmail.com[2]
Center for Communication, Media and Information Technologies, Aalborg University, Copenhagen, Denmark[3]
E-mail: skouby@cmi.aau.dk[3]

***Abstract*—Current wireless technologies allow limited flexibility in selection of operating frequency of the wireless devices. Cognitive radio is the potential candidate for the efficient spectrum usage in future due to its ability to modify their operational parameters such as frequency, modulation schemes, and transmit power. Several measurements have shown that the current spectrum is inefficiently utilized. The inefficient utilization problem can be solved with the help of Dynamic Spectrum Access. This paper describes the GSM band measurement conducted at different locations. In this paper, we report detailed measurement results of GSM band including statistical as well as spectral occupancy details obtained from measurement campaign conducted in Pune, India for indoor and outdoor scenarios. The results can be further used as an input for spectrum regulator for considering Cognitive Radio (CR) operation in GSM band.**

Keywords-Dynamic spectrum access (DSA), Cognitive Radio, Spectrum occupancy

I. Introduction

During recent years, flexibility and adaptability of wireless devices has been considerably improved for efficient spectrum usage but it comes along with increased complexity. Cognitive Radio [1], [2] is a paradigm for wireless communication in which wireless node changes its transmitting parameters according to its radio environment for efficient and reliable communication and avoiding interference with licensed or unlicensed users. The cognitive radio has ability to dynamically optimize the operating parameters like frequency and bandwidth according to RF environment variations [3]. By applying the CR technique the deficiency of the spectrum can be overcome.

Several measurement results [4]–[11] have showed poor spectrum utilization of the licensed spectrum. All these measurement campaigns have shown significant amount of unused spectrum both in frequency and time domain. The unused spectrum termed as white space were found despite of the fact that most of the spectrum is licensed. This has led to the conclusion that the current spectrum regulation is highly inefficient. The Dynamic Spectrum Access (DSA) vision tries to solve this problem and improve the efficiency of spectrum usage. The unlicensed users which are also termed as secondary users sense the unused spectrum bands and opportunistically use those without harmful interference to licensed users also sometimes referred as primary users.

The availability of the frequencies and further development of algorithm for efficient frequency allocation in cognitive radio network can be derived from the statistical information of frequency usage in the primary network. The major contribution of this paper is to present the current spectrum usage of GSM band in India using the real time measurements performed at Pune, India in the frequency band 700-2746.6 MHz.

The remainder of this paper is structured as follows. Section II describes measurement setup and methodology. Section III explains the different scenarios at which the measurements were taken. The data collected in the different scenarios is used to obtain the results like spectrum occupancy, PSD plot and histogram etc. which are explained in section IV. The conclusion drawn from the results is discussed in section V.

II. Measurement Setup

The measurement setup consist of spectrum analyzer, a laptop and an antenna (see figure 1). A Rohde and Schwarz (FSH3) spectrum analyzer [12], [13] was interfaced with laptop (DELL) via an optical cable. The spectrum analyzer was programmed to save real-time information about the spectrum in the laptop's hard disk. AOR DA 5000 antenna is used in this campaign. It is specially designed for the frequency range of 700 MHz to

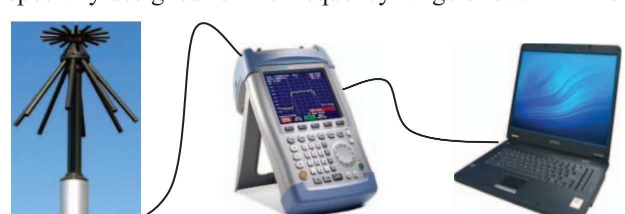

Figure 1. Measurement equipment configuration.

3GHz. The antenna is connected to spectrum analyzer through a low loss coaxial cable. The details of measurement set up, methodology and spectrum analyzer configuration are specified in [11].

For data collection, program is written in the Remote Control software of FSH using the commands for spectrum analyzer. The program is executed for the number of times as per the count given in loop. We set the loop such that data collection goes on continuously without interruption for complete 48 hours. The files are collected in .CSV format. These files can be opened in Microsoft excel. Then the data is processed and viewed for analysis and comparison. The stored data is processed using the MATLAB software package, and the data is converted to a more understandable format for future analysis.

To distinguish noise from active primary signal threshold is necessary. Threshold setting is considered to be the most crucial step in evaluation of spectrum occupancy. Most spectrum occupancy measurement methods adopt fixed threshold which usually distinguish signal from noise. Once the power level exceeds a threshold, it will be considered as active signal, otherwise as noise. We have obtained the average noise level by connecting a 50Ω termination to spectrum analyzer. The decision threshold is set by adding 3 dB in measured thermal noise. The decision threshold obtained with this method is not constant since the system noise slightly increases with the frequency.

III. Scenario Description

The spectrum measurement was conducted at four locations from February 2011 to March 2012. The brief description of locations is given in table I [11]. The detail explanation of the different scenarios is given below.

TABLE I. Measurement Locations At Pune [11]

Name	Brief Description of Location
SAE, Outdoor Location 1	Roof top of the Building of Sinhgad Academy of Engineering Latitude: 18º 26’ 36.4” North, Longitude: 73º 53’ 44.5” East.
SAE, Indoor Location 2	Room located on second floor of the Sinhgad Academy of Engineering Latitude: 18º 26’ 36.7” North, Longitude: 73º 53’ 45.6” East.
SBS, Outdoor Location 3	Roof top of the Building of Sinhgad Business School Latitude: 18º 30’ 29.6” North, Longitude: 73º50’7.1” East
CB, Outdoor Location 4	Roof top of the Commercial Building on Law college road Latitude: 18º 50’ 34.04” North, Longitude: 73º 49’ 51” East

A. Scenario 1 (Outdoor measurement)

The outdoor measurement was taken on the roof top of Sinhgad Academy of Engineering (SAE) College building (see figure 2). SAE is located at outskirts of Pune city with small scale industries on one side and rural area other side. Being an educational site the nearby area has many hostels. The measurement point is high so that all nearby residential buildings below measurement point. The south side of location is surrounded by vast open areas. In surrounding area there is no other building to block the radio propagation significantly. The cellular base station transmitters are in direct line sight with the measurement location. The data collection was started at 8:00 AM on 17th Feb 2011and stopped at 8:00 AM on 19th Feb 2011.

Figure 2. Outdoor measurement set up.

B. Scenario 2 (Indoor Measurement)

The measurement was taken inside the SAE college building for consecutive two days. The measurement setup was kept in the room as shown in figure 3. The measurement was started at 9:30 AM on 27th Feb 2011 and stopped at 9:30 AM on 29th Feb 2011.

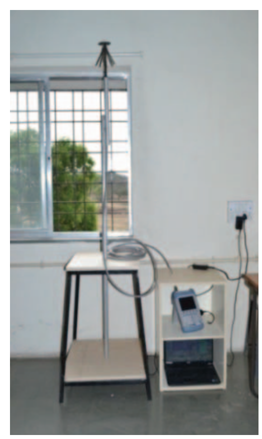

Figure 3. Indoor measurement set up.

C. Scenario 3 (Outdoor measurement)

Spectrum utilization is comparatively more in urban areas than suburban areas. Hence we have selected the next spectrum measurement campaign in urban crowded place within Pune city at Sinhgad Business School. The area is surrounded by school, college, malls, shops and software companies. There are many base stations in the vicinity of this location. The data collection started at noon on 7th March 2011 and stopped on 9th March 2011.

D. Scenario 4 (Outdoor measurement)

The fourth measurement location is situated on law college road and considered as busy location of Pune city. The set up was installed on a roof top of a six floor commercial building. This location has dense population compared to the first two locations. The area is surrounded by IT companies, residential buildings, hotels and restaurants. The main roads are very close to measurement location. The data collection started at 7 AM on 12th March 2012 and stopped on 14th March 2012 at 7 AM.

IV. MEASUREMENT RESULTS

A. Complementry Cummulative Distribution Function (CCDF)

In probability theory and statistics, the cumulative distribution function (CDF), or just distribution function, describes the probability that a real-valued random variable X with a given probability distribution will be found at a value less than or equal to x. The CDF of a continuous random variable X with probability distribution function f is given by

$$F(x) = \int_{-\infty}^{x} f(t)dt$$

CCDF shows how often the random variable is above a particular level. Thus, CCDF is obtained by

$$\text{CCDF} = 1 - F(x)$$

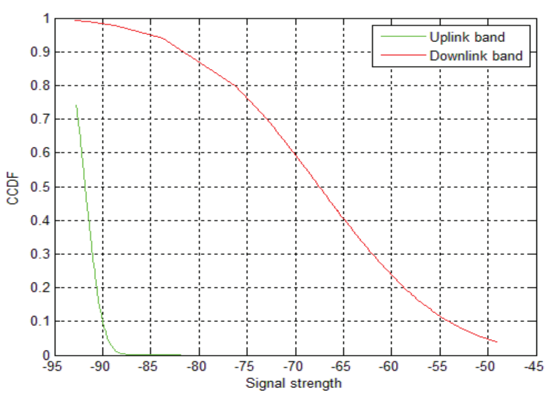

Figure 4. CCDF of GSM 900 band for scenario 1.

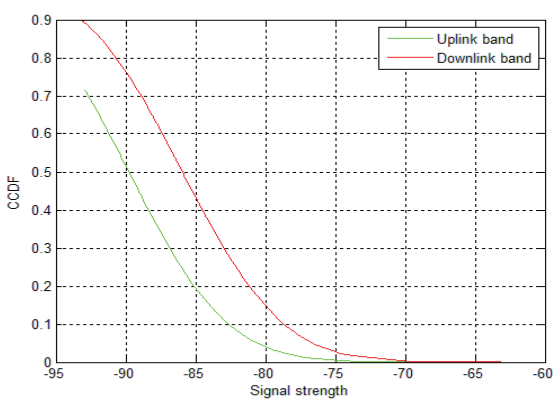

Figure 5. CCDF of GSM 900 band for scenario 2.

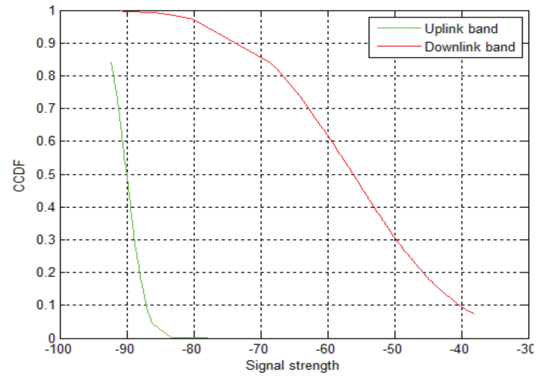

Figure 6. CCDF of GSM 900 band for scenario 3.

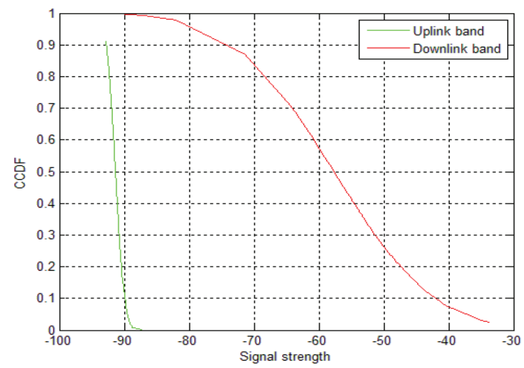

Figure 7. CCDF of GSM 900 band for scenario 4.

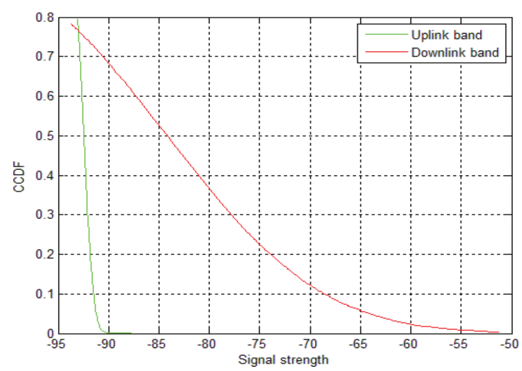

Figure 8. CCDF of GSM 1800 band for scenario 1.

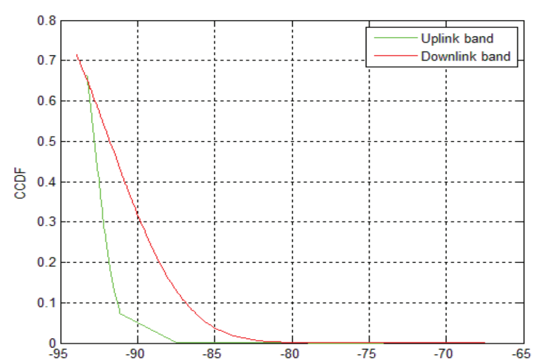

Figure 9. CCDF of GSM 1800 band for scenario 2.

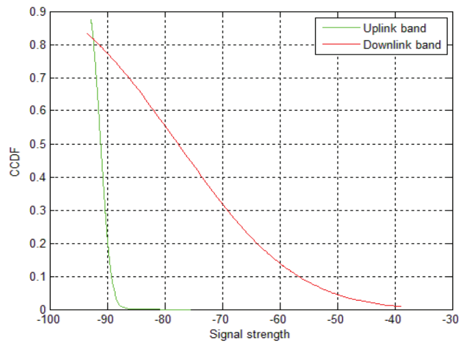

Figure 10. CCDF of GSM 1800 band for scenario 3.

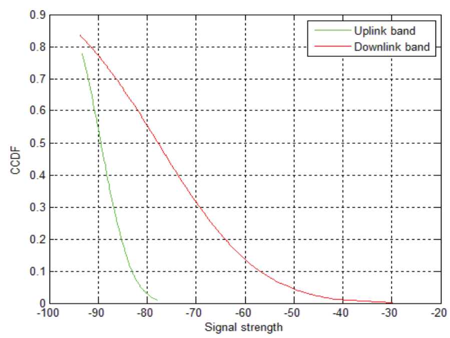

Figure 11. CCDF of GSM 1800 band for scenario 4.

Figure 4-11 shows CCDF curves for the GSM 900 and GSM 1800 band for four scenarios. Figure shows CCDF curves for two bands: downlink (DL) and uplink band(UL). The DL band (red line) operates at high power level than UL band (green line). The DL curves has moderate slope while UL band curve has large slope for both GSM bands.

The uplink band signal strength varies around noise level for outdoor for both GSM bands showing potential for cognitive radio operation at outdoor location for GSM 900 and 1800 band. The primary signal activity for scenario 2 seems to be more than scenario 1 for both GSM 900 as well as GSM 1800. The fall in the downlink CCDF curve for GSM 900 and 1800 is sharper for indoor scenario due to no direct line of sight for signal and attenuation from walls.

CCDF curves for outdoor scenarios are similar for both GSM bands. The downlink of GSM 1800 shows low power level compared to GSM 900 band. DL curves consistently shows high power level as continuous transmission of control channels from base stations with high power. Downlink channels of GSM 1800 have highest signal strength in scenario 4 as compared to the other three scenarios and this may be due to the measurement location being close to base stations.

B. Power Spectral Density (PSD) Plot

Figure 12-13 shows average PSD variation for GSM 900 and GSM 1800 band for four scenarios. For outdoor measurement the power level in down link is observed higher (since it is in direct line of site with base station) than indoor location as the signals get severely attenuated by walls in indoor. The DL channels of GSM band is fully occupied as there is continuous transmission with relatively high power for updating the procedures from base station. The usage of uplink channels varies according to the active users on network. We have also observed the GSM 900 mobile unit radiate more power than the GSM 1800 mobile unit. We have also noted that the uplink channel power level more in indoor than outdoor in GSM 900 and 1800. This may be due to the calls generated from nearby area of indoor measurement location.

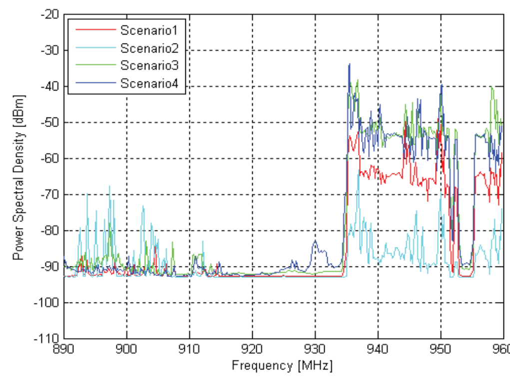

Figure 12. PSD of GSM 900 for all scenarios

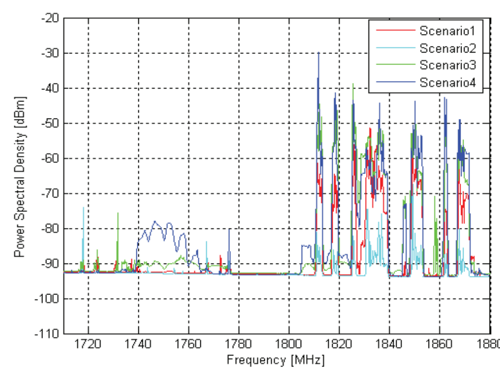

Figure 13. PSD of GSM 1800 band for all Scenarios.

C. 3-D Histogram

A 3-D histogram is a three dimensional plot that displays the power of the signal verses time and frequency. The vertical axis represents time, the horizontal axis represents frequency and the third axis represents power level.

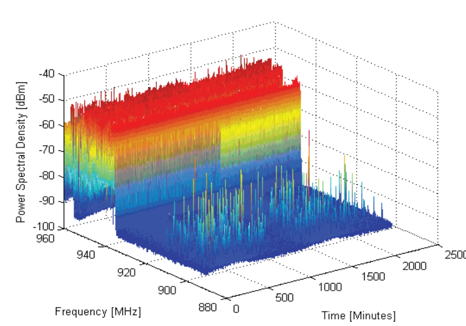

Figure 14. 3D Histogram of GSM 900 for Scenario 1.

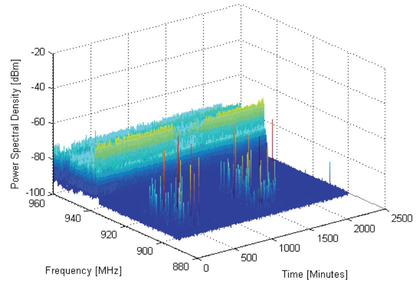

Figure 15. 3D Histogram of GSM 900 for scenario 2.

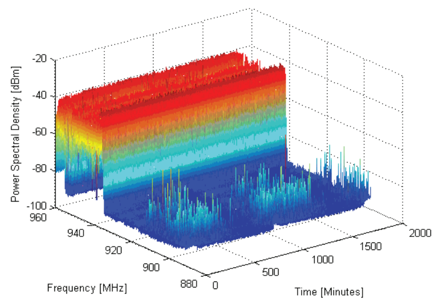

Figure 16. 3D Histogram of GSM 900 for scenario 3.

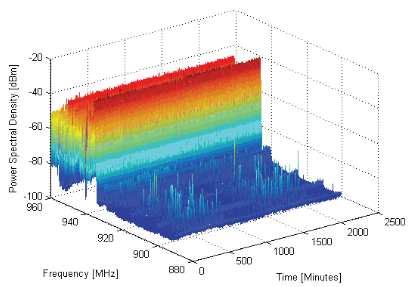

Figure 17. 3D Histogram of GSM 900 for scenario 4.

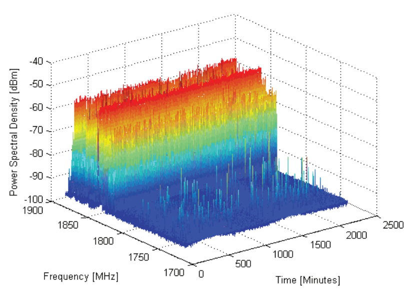

Figure 18. 3D Histogram of GSM 1800 for Scenario 1.

The band gap between the uplink and downlink is observed prominently from above figures. The signal strength after the time zone 1000 minute and before 1400 (i.e. during night) is almost zero for both the outdoor and indoor. These temporal white spaces can be used for cognitive radio. The primary signals activity in indoor is only observed during college working hours. There is a higher probability of the channel to be vacant in GSM 1800 uplink band than GSM 900 for secondary use.

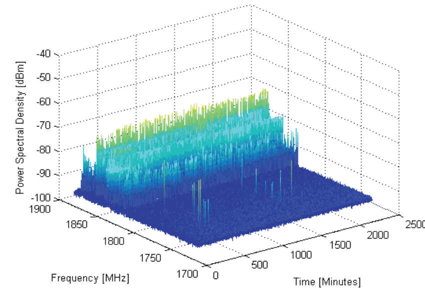

Figure 19. 3D Histogram of GSM 1800 for Scenario 2.

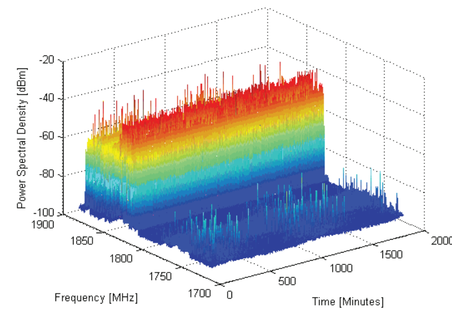

Figure 20. 3D Histogram of GSM 1800 for Scenario 3.

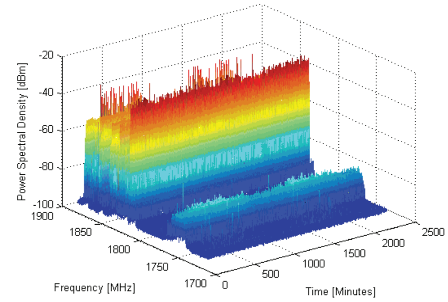

Figure 21. 3D Histogram of GSM 1800 for Scenario 4.

Figure 14-21 shows the probability of finding a band vacant is higher in indoor scenarios than outdoor scenarios. Thus, the probability of finding the channel vacant depends on location i.e. indoor or outdoor.

Figure 15 and 19 shows that the indoor scenario has very low occupancy during the day time and trifling during the night which indicates potential for cognitive radio.

In figure 21, the frequency range 1740-1765 MHz shows occupancy during the complete measurement period of 48 hours which clearly indicate that this particular band is not suitable for cognitive radio application. The down link occupancy is observed higher in case of GSM 900 band than GSM 1800 band.

D. GSM band Occupancy

The general utilization of GSM band is necessary to find spectrum opportunities for secondary usage. Let Ω_{t_m,f_n} denote the spectrum occupancy at time index t_m and channel index f_n, defined as

$$\Omega_{t_m,f_n} = \begin{cases} 0, & P_r < \lambda \\ 1, & P_r \geq \lambda \end{cases}$$

P_r is the received PSD measured in channel f_n and at time index t_m. λ is decision threshold. If $\Omega_{t_m,f_n} = 1$ a primary user signal is detected and the channel is occupied. PSD values below λ indicate a free channel. The average spectrum occupancy of the GSM 900 band can be calculated by

$$\Omega = \frac{1}{M.N} \sum_{m=1}^{M} \sum_{n=1}^{N} \Omega_{t_m,f_n}$$

The percentage average spectrum utilization found in GSM 900 and 1800 band is given in Table II. The noise varies with the frequency so the decision threshold is not taken as fixed for GSM 900 and 1800 band. The decision threshold is set by adding 3 dB in the measured thermal noise. The decision threshold set for GSM 900 is -90.2 dBm and -90.56 dBm for GSM 1800 band.

TABLE II. SPECTRUM OCCUPANCY FOR SCENARIO 1,2,3 AND 4

Frequency band	Occupancy (%) for Scenario 1	Occupancy (%) for Scenario 2	Occupancy (%) for Scenario 3	Occupancy (%) for Scenario 4
GSM 900 UL	1.32	0.19	9.44	9.18
GSM 900 DL	86.05	54.62	93.23	96.51
GSM 900 Band	31.41	19.44	38.79	46.28
GSM 1800 UL	0.86	0.086	24.3	30.96
GSM 1800 DL	37.03	14.82	54.82	59.46
GSM 1800 Band	16.76	6.59	35	40.09

The table II shows that the uplink and down link occupancy is not identical for GSM bands at indoor and outdoor location. The downlink band occupancy is higher than uplink as expected due to continuous transmission of signal on control channels. The spectrum occupancy for outdoor is observed high as compared to indoor. The uplink occupancy at both the scenarios is less indicating high scope for dynamic spectrum access.

V. CONCLUSION

The GSM band measurements showed the dependency of spectrum occupancy on the measurement location and the decision threshold. The information of location in future CR system will be essential for efficient operation. The decision threshold is one of the important contributing factors in determining the occupancy of the band as, if the decision threshold is considered higher than the average noise floor the weak signals will also be considered as noise which will result in incorrect occupancy. On the other hand if the threshold considered is less than the average noise, some noise will be considered as signal which will also lead to incorrect occupancy.

The occupancy results of GSM 900 and 1800 band leads to the conclusion that the bands are underutilized. The GSM uplink band has considerable scope for cognitive radio operation. The 3D histogram shows that the uplink band usage of GSM 900 and 1800 band at night is almost zero. Thus, the band can be used for cognitive radio during night time without causing any interference to the primary users.

This result provides the opportunity for regulators and operators to know the extent to which the spectrum is utilized and its variation over time.

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