**Indonesian Journal of Electrical Engineering and Informatics (IJEEI)**
Vol. 7, No. 3, Sep 2019, pp. 508~518
ISSN: 2089-3272, DOI: 10.11591/ijeei.v7i3.1094 

# Spatial Variability Study of Duty Cycle in GSM 900 and 1800 MHz Bands in Rural and Urban Environments

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**Article Info**

***Article history:***

Received Mar 7, 2019
Revised Apr 30, 2019
Accepted Aug 26, 2019

***Keyword:***

Duty Cycle
GSM band
Rural
Urban
Spatial

**ABSTRACT**

This paper examines the spatial variability of duty cycle in the GSM 900 and 1800 MHz bands within Kwara State, Nigeria. The results show spatial variance in the duty cycle with average occupancies of 1.67%, 17.76%, 10.55% and 0.39%, 11.00% and 5.11 in the rural, urban and all locations for 900 and 1800 MHz bands. Findings also show that there is very high positive correlation between rural 900/1800 MHz and urban 900/1800 MHz. But very high negative correlations exits between urban 900 and rural 1800, and urban 1800 and rural 1800. There is a weak and negative correlation between rural and urban 900 MHz, rural-urban 1800. These results clearly show the abundance of unutilised spectrum within the GSM bands. Therefore, regulatory commissions should adopt flexible spectrum reuse strategy to relax the regulatory bottlenecks to maximize the scarce radio resources in the licensed bands, especially for rural network deployments



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## 1. INTRODUCTION

Globally, there is unprecedented growth in mobile data traffic, mostly driven by increase of data-intensive devices, such as tablets and smartphones. Efficient usage of the scarce electromagnetic spectrum is necessary for sustenance of more advanced services such as the Internet of Things (IoT), Internet of Vehicle (IoV), remote sensing and many others. However, despite the notion of the scarcity of the radio spectrum, considerable portion of the spectrum set available for wireless communications have been largely underutilized. This underutilization arises due to the current command and control model that largely protects the licensed spectrum owners who may not use the spectrum at all times in all places [1]. This model fails to address the secondary spectrum market opportunities that could not only provide more spectral spaces for the aforementioned services but could also bridge digital divide in most developing economies. The gap is widening as the majority of the unconnected are in the rural areas with communities characterised by extreme poverty, lack of, or limited, social services and infrastructure [2].Thus, it becomes highly necessary to develop techniques that will enhance efficient spectrum utilization, free more spectral spaces that could meet the need for the exponential growth in global mobile data traffic and be used as a tool for meeting up the Sustainable Development Goals (SDGs).Such flexible spectrum regime has been identified as the driver for solving these issues [3].

In an effort to tackle the foregoing issues, Cognitive Radio (CR) approach was introduced [4]. The basic underlying idea of CR is to give room for unlicensed access to some unoccupied licensed bands temporarily or spatially in a favorable, non-interfering and symbiotic manner [5]. In recent time, spectrum occupancy measurement and survey has experienced a rapid growth in Africa, Asia and Europe [4-9]. However most of the researches have not significantly explored spectrum opportunities on the GSM bands. More so, considering the economic viability of the sub 3 GHz spectrum (1.5 GHz to 3 GHz), it would be uneconomical to deploy these bands in the rural environments as it leads to high deployment and operating costs [10]. Fortunately, spectrum refarming in the GSM band is still possible as in contrast to the global view to explore only Television White Spaces (TVWs). This has been introduced and demonstrated in [11-12]. It is worthy acknowledging the efforts of Martin in [13] that examined how the spatio-temporal properties of spectrum holes affects the basic communication needs of a secondary spectrum user. Also, Babalola *et al.* [14-15] studied the temporal variation of duty cycle in the TV band and Faruk *et al*. [16] conducted a large scale spectrum survey in the rural and urban locations spanning 50 MHz- 6 GHz. In [17], a 15-day measurement was conducted outdoors at Selcuk University, Faculty of Engineering building, Konya. The measurements were conducted in both urban and suburban areas covering VHF and UHF bands. After the analysis of the measurement data, it was observed that the part of spectrum lower than 1 GHz is used massively. However, spectrum part above 1 GHz is almost idle. Measurements conducted in the urban area in context of spectrum occupancy resulted in 18.07% and 11.17% for both VHF and UHF respectively. For the suburban area, the spectrum occupancy results area 9.80% and 10.84% for both VHF and UHF respectively. Attiah et al [18] investigated the implementation of a flexible hybrid mmWave spectrum sharing access (HMSSA) strategy for 5G networks. In [19], spectrum occupancy measurements were conducted in different classes of urban environments in Melbourne, Australia. The uniqueness of this investigation is that the measurement was conducted on a mobile vehicle for assessment on spatial perspective considering a wide frequency band which ranges from 400 MHz to 6000 MHz.

In this paper, we examinedthe spatial variability of spectrum occupancies (duty cycle)in the GSM 900 MHz and 1800 MHz bands in some selected rural and urban areas in Kwara State, Nigeria. The objective of the paper is to explore spectral opportunities in the GSM band for refarming or secondary reuse and to study if there is correlation between the variability indices across the bands in different locations. These would guide policy makers to make more informed decisions on the spectrum opportunities that may arise in the GSM bands.

## 2. METHODOLOGY

### 2.1. Measurement Setup

Agilent N9342C Handheld Spectrum Analyzer (HSA) was used as the receiver. The analyser has a frequency span of 100 kHz to 7 GHz and with a display average noise level of -164 dBm/Hz. The measurement setup and settings used are identical in both rural and urban locations. The analyzer uses energy detection to directly sense the received signal level in dBm. It is capable of displaying the spectrograph of signals. It also has both in-built GPS (global positioning system) for location features.

Figure 1. Agilent N9342C Spectrum analyzer

However, for improved location accuracy, an external GPS was connected to it. An external storage device was used to save the log files generated by spectrum analyser as shown in Figure 1.

### 2.2. Measurement Locations

The measurements were all conducted outdoors at strategic rural and urban locations in Kwara state, Nigeria. Table 1 shows the measurement sites and type of environment considered, with their respective coordinates. Table 2 shows the frequency bands considered. Five rural locations visited are within 30 miles (about 50 km) radius from the metropolis.

Table 1. Location Visited

| Location | Type | Coordinate | Identifier |
|---|---|---|---|
| Adio village | Rural | 4°29'42"E 8°46'40"N | LOC 1 |
| Malete Village | Rural | 4°31'16"E;8°38'49"N | LOC 2 |
| Alamote Village | Rural | 4°29'42"E 8°22'34"N | LOC 3 |
| OdoOke Village | Rural | 4°31'55"E 8°17'09"N | LOC 4 |
| Lagiki, Village | Rural | 4°33'02"E 8°16'46"N | LOC 5 |
| University Quarters | Urban | 4°38'47"E 8°27'49"N | LOC 6 |
| University of Ilorin | Urban | 4°67'60"E 8.48'74"N | LOC 7 |
| Pipeline | Urban | 4°35'07"E 8°27'57"N | LOC 8 |
| Kwara Stadium | Urban | 4°32'29"E 8°28'36" N | LOC 9 |

The urban locations were specifically chosen due to high activity of mobile users. This is to reflect the reality of the spectrum usage.

Table 2. Service Bands Considered

| Service Bands | Frequency range (MHz) | Bandwidth (MHz) |
|---|---|---|
| GSM 900 UL | 835-915 | 80 |
| GSM 900 DL | 925-960 | 35 |
| GSM 1800UL | 1710-1785 | 75 |
| GSM 1800DL | 1805-1880 | 75 |

### 2.3. Data Collection and Processing

During data collection, the sensed signals are collected and stored in external drive for processing. The unprocessed data are presented in a 2X2 matrix form with element of the received signal power for each frequency and at specific time slot, ($f_i$, $t_j$). During data pre-processing stage, the received data was mined to filter noisy data entries, transposed and sorted. The preamplifier was set and appropriate resolution bandwidth chosen. For each sweep, 1500 frames were collected. Each frame has 114 time slots as represented by the received signal power matrix given by Equation (1).

$$P = \begin{pmatrix} P(f_1,t_1) & . & . & . & P(f_1,t_j) \\ . & . & . & . & . \\ . & . & . & . & . \\ . & .. & .. & . & . \\ P(f_i,t_1) & . & . & . & P(f_i,t_j) \end{pmatrix} \tag{1}$$

The energy detection technique was used as the sensing approach due to its simplicity and ease of computation. Moreover, it has been the most widely used by many researchers. Among the 1500 frames collected for each location per band, 50 frames were selected at random within the sample space. This is because the frame size above 50 was found to have insignificant impacts on the average duty cycle since 10 frames can still provide satisfactory results [20].

Equation (2) was used to obtain the decision '$\Omega$' of the output of the energy detector. This is achieved by satisfying the hypothesis ($H_1$, signal is present or $H_0$, signal is absent). For the detection threshold, we used 5 dB above the mean measured noise level. This threshold was found to provide optimum duty cycle prediction [20] as its prediction was on the borderline, not under estimation as obtained with 3 dB or over-estimation when 10 dB was used [20].

$$\Omega_D = \begin{cases} \mathrm{H}_1, & \text{if } P > \lambda_j \\ \mathrm{H}_o, & \text{if } P < \lambda_j \end{cases} \tag{2}$$

Then, the duty cycle was obtained as:

$$\Psi(x, f, t) = \frac{1}{M} \sum_{N} \sum_{i=1}^{\tau} \Omega_D(f_i, t_j) \quad (3)$$

Where $\Psi(x, f, t)$ represent the duty cycle for specific frequency of a given location at specific time. $\Omega_D(f_i, t_j)$ is the sample of power of a given frame, when $P(f_i, t_j) > \lambda_j$. $M$ is the total observation period. $\tau$ is the signal duration and $N$ is the frame number.

## 3. RESULTS AND DISCUSSION

The results of the various occupancy measurements in the GSM 900 MHz and 1800 MHz DL for both the rural and urban locations in Ilorin Kwara State are shown in Tables 3 and 4. In Table 3, a duty cycle of 0.07% was obtained for LOC1 (rural), a significant increase (6.9%) was observed in LOC 2. LOCs 4 to 5 were completely unoccupied with duty cycle of 0%. The reason for this spatial variation is that LOC 2, being a rural area, has experienced technological developments including being the host to a state university in Kwara state, Nigeria.

Table 3. Duty Cycle Results for GSM 900 MHz

| LOCATION | LOCATION TYPE | DUTY CYCLE (%) | AVERAGE DUTY CYCLE PER LOCATION TYPE | AVERAGE DUTY CYCLE |
|---|---|---|---|---|
| LOC 1 | RURAL | 0.07 | 1.67% | 10.55% |
| LOC 2 | RURAL | 6.91 | | |
| LOC 3 | RURAL | 1.39 | | |
| LOC 4 | RURAL | 0 | | |
| LOC 5 | RURAL | 0 | | |
| LOC 6 | URBAN | 9.04 | 17.76% | |
| LOC 7 | URBAN | 8.04 | | |
| LOC 8 | URBAN | 19.28 | | |
| LOC 9 | URBAN | 34.69 | | |

Table 4. Duty Cycle Results for GSM 1800 MHz

| LOCATION | LOCATION TYPE | DUTY CYCLE (%) | AVERAGE DUTY CYCLE PER LOCATION TYPE | AVERAGE DUTY CYCLE |
|---|---|---|---|---|
| LOC 1 | RURAL | 0.69 | 0.39% | 5.11% |
| LOC 2 | RURAL | 1.24 | | |
| LOC 3 | RURAL | 0 | | |
| LOC 4 | RURAL | 0 | | |
| LOC 5 | RURAL | 0.02 | | |
| LOC 6 | URBAN | 0.12 | 11.00% | |
| LOC 7 | URBAN | 0.1 | | |
| LOC 8 | URBAN | 11.89 | | |
| LOC 9 | URBAN | 31.9 | | |

The results show that the GSM 900MHz band is slightly occupied in LOC1 and most occupied in the LOC 2, while all other rural locations were completely unoccupied. For urban locations, LOCs 6 and 7 exhibit high occupancy level. But a quite higher occupancy rateof 19.28% and 34.69% were observed in LOCs 8 and 9 respectively. This is because the locations considered (i.e. 8 and 9) are residential and commercial areas respectively within the metropolis, as such high activities are expected. Average occupancies of 1.67% and 17.76% were recorded in the rural and urban locations respectively with an overall of 10.55% in all locations.

Table 4 provides duty cycle for GSM 1800 MHz DL across the rural and urban locations. Similar findings were obtained for rural and urban locations. As expected, the spectrum is occupied in the urban areas and highly underutilised in the rural locations. The occupancies obtained in the case of GSM 900 MHz are quite high than 1800 MHz across all locations. This is an indication that the 900 MHz band is more utilised. The average occupancies of 0.39%, 11.00% and 5.11% were measured respectively for the rural, urban and across the nine locations.

Table 5. Pearson's Correlation Matrix

| | Rural 900 MHz | Rural 1800 MHz | Urban 900 MHz | Urban 1800 MHz |
|---|---|---|---|---|
| Rural 900 MHz | 1.0000 | 0.8003 | -0.54026 | -0.5081 |
| Rural 1800 MHz | 0.8003 | 1.000 | -0.81047 | -0.7780 |
| Urban 900 MHz | -0.54026 | -0.8104 | 1.0000 | 0.9986 |
| Urban 1800 MHz | -0.50811 | -0.7780 | 0.998574 | 1.0000 |

**. Correlation is significant at the 0.01 level (2-tailed).

In Table 5, we provide the Pearson's correlation coefficient matrix of the duty cycle across the bands and locations. From the table, we could see that there is very high positive correlation between rural 900 MHz and rural 1800 MHz bands, urban 900 MHz and urban 1800 MHz with correlation coefficients of 0.8 and 0.9 respectively. However, very high but negative correlations were obtained for urban 900 MHz and rural 1800 MHz, and then urban 1800 MHz and rural 1800 MHz. A weak and negative correlation was obtained for rural and urban 900 MHz. The correlation for rural-urban 1800 MHz was also negative but higher than for 900 MHz band.

Figures 2 and 3 show the cumulative distribution function of the received signal strength for six locations, three rural and three urban, for GSM 900 MHz and 1800 MHz bands respectively. From both figures, LOC 6 recorded the best signal quality based on this metric. These results indicate that higher duty cycle does not directly mean better signal quality, as the duty cycle is a measure of occupancy (i.e. when the received signal exceeds the threshold value defined). Therefore, values of –60 dBm and -90 dBm could mean the same occupancy. In other words, methodology in computing the duty cycle metric did not cater for temporal variation of the received Signal Level (RSS).

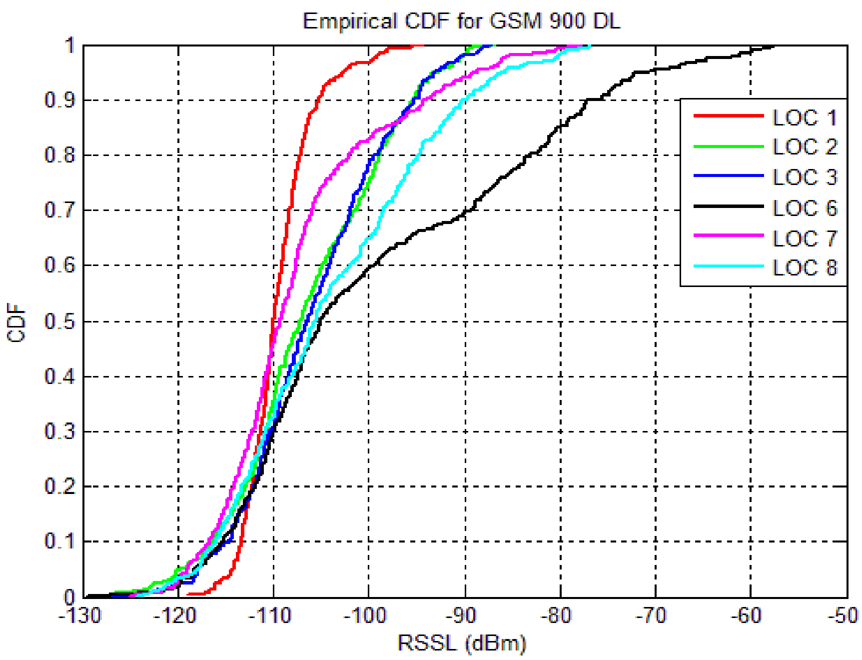


Figure 2. Cumulative Distribution for Received Signal Strength in the GSM 900 MHz Band for selected Locations

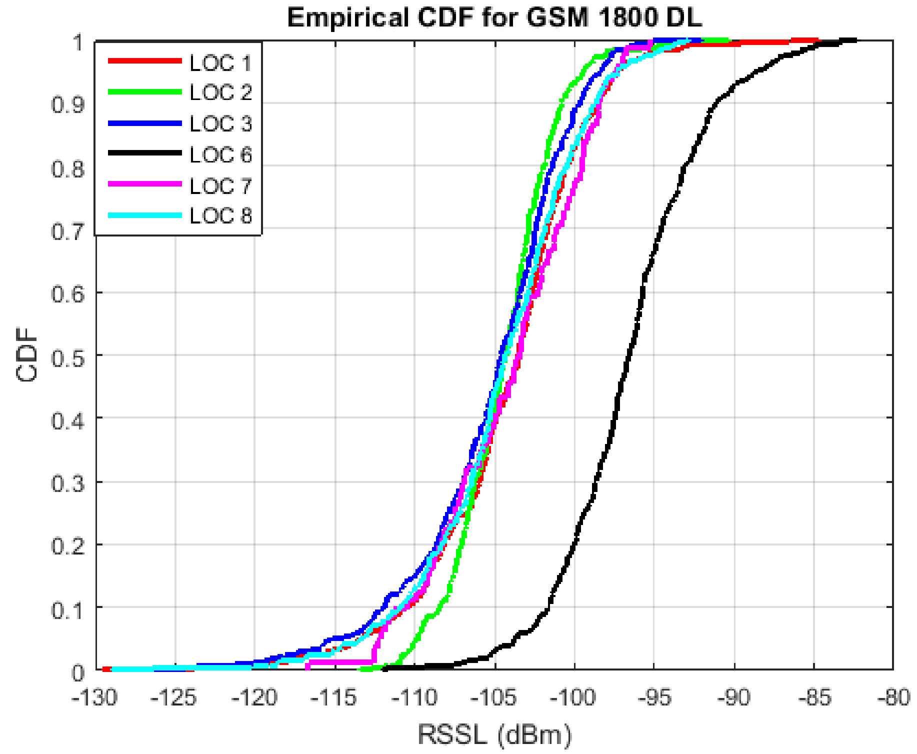


Figure 3. Cumulative Distribution for Received Signal Strength in the GSM 1800 MHz Band for selected Locations.

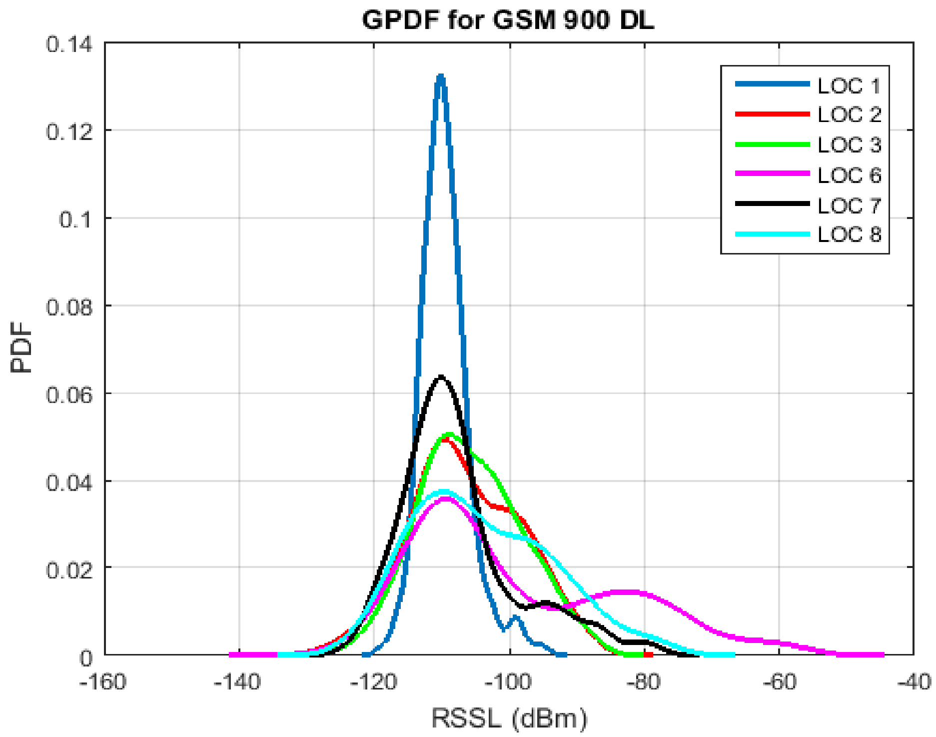


Figure 4. probability Density function for the Received Signal Strength in the GSM 900 MHz Band for selected Locations

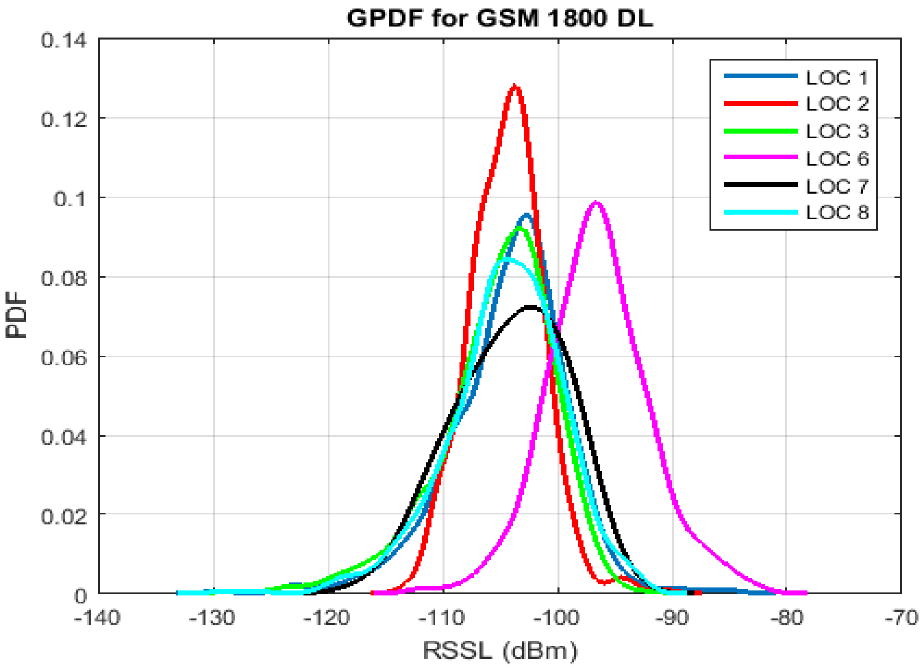


Figure 5. probability Density function for the Received Signal Strength in the GSM 1800 MHz Band for selected Locations

In Figures 4 and 5, we show how the received signal levels are distributed. The results show that Gaussian normal distribution can perfectly be used to represent the distribution of the RSSLs, with locations 1 and 7 showing perfect normal distribution in 900 MHz band, while all the RSSLs for all the locations are normally distributed in the 1800 MHz band. Figs 6 to 11 show the spectrograms of the spectrum occupancy for some selected rural and urban locations. The spectrograms show the location dependent variation of the duty cycle over time.

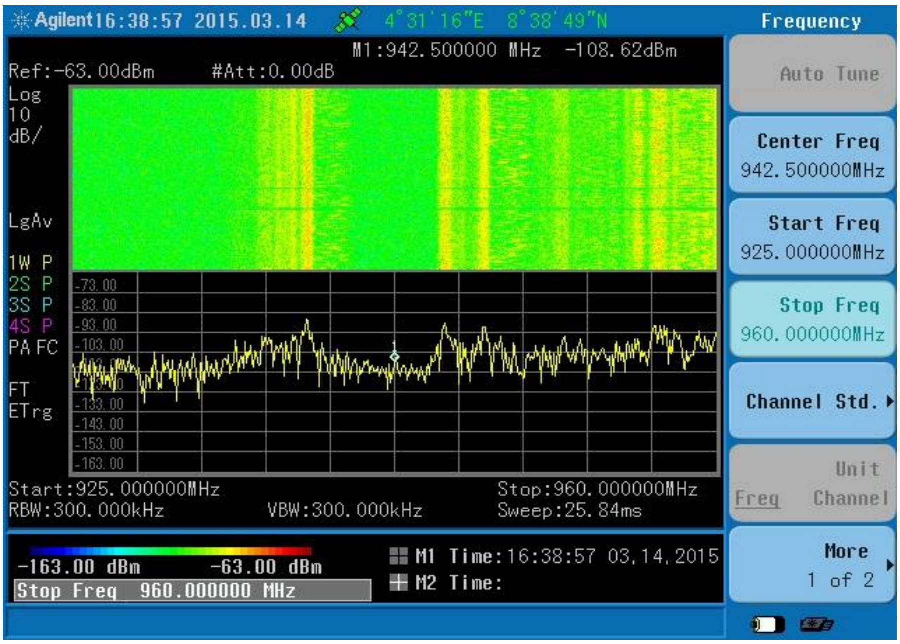


Figure 6. Spectrogram for Location 2 (Malete Village, 4°31'16"E 8°38'49"N) for GSM 900 MHz

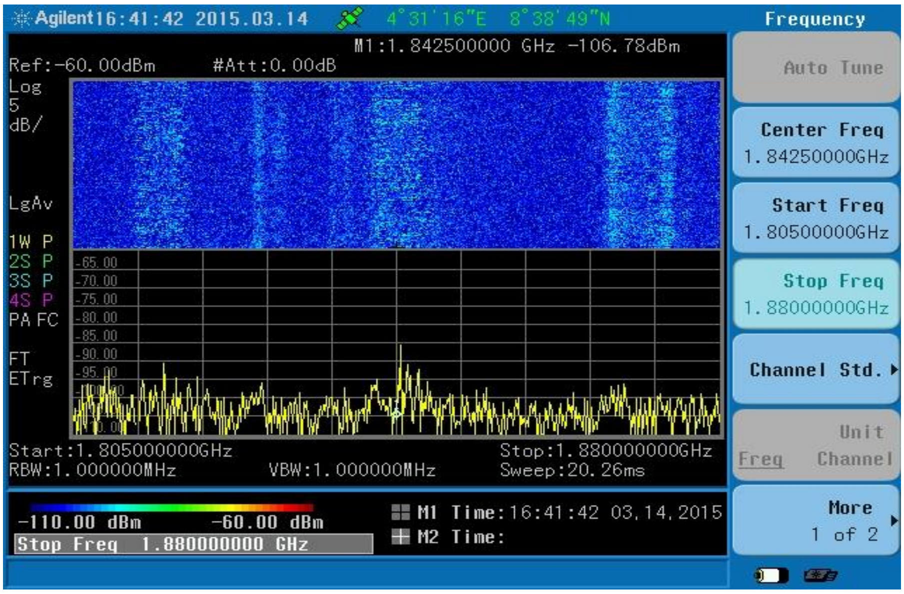


Figure 7. Spectrogram for Location 2 (Malete Village, 4°31'16"E ;8°38'49"N) for GSM 1800 MHz

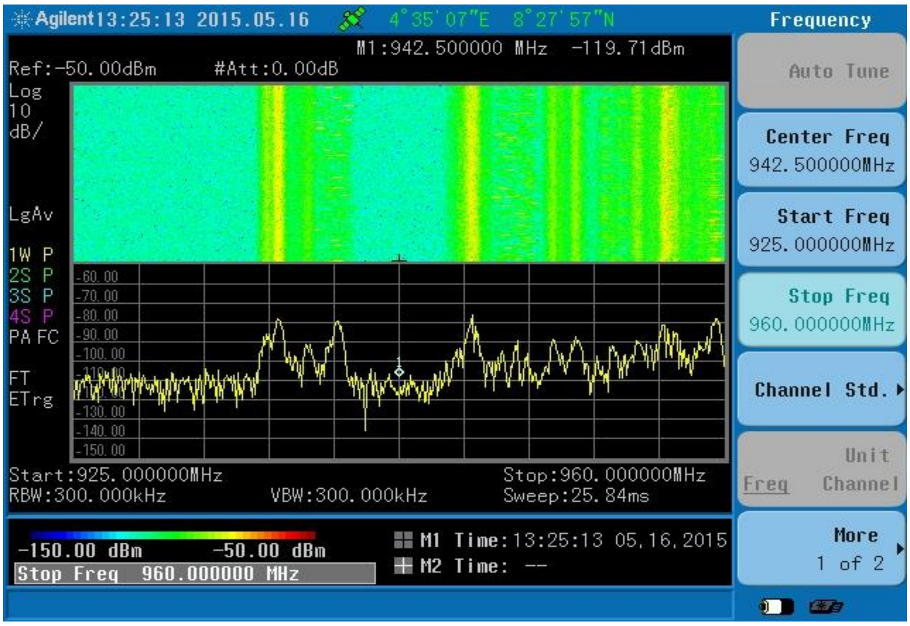


Figure 8. Spectrogram for Location 8 (Pipeline) for GSM 900 MHz

In Figures 6 and 7 we provide the spectrograms for the occupancy of LOC 2 (Malete Village, 4°31'16"E; 8°38'49"N) for GSM 900 MHz and 1800 MHz bands. This location is categorised as rural and it could be that no significant activity going on within the bands. However, the spectrum is weakly occupied in the 900 MHz band with occupancy value of 6.9%. Weak signal is spotted on the 1800 MHz as noise, instead of signal, was basically measured. In Figs. 8 to 11 we provide the spectrograms for the occupancy of LOC8 (Pipeline) and LOC 9 (Kwara State Stadium) each for GSM 900 MHz and 1800 MHz bands. All these locations are categorised as urban and significant activities were noticed within the bands. The Pipeline location recorded average spectrum occupancies of 19.28% and 34.69% respectively for 900 MHz and 1800 MHz bands. Similarly, the average occupancies of 11.89% and 31.9% were measured in Kwara State stadium. These two locations recorded the highest occupancy values. These findings further indicate the spatial variance of the duty cycle across the locations and frequency bands.

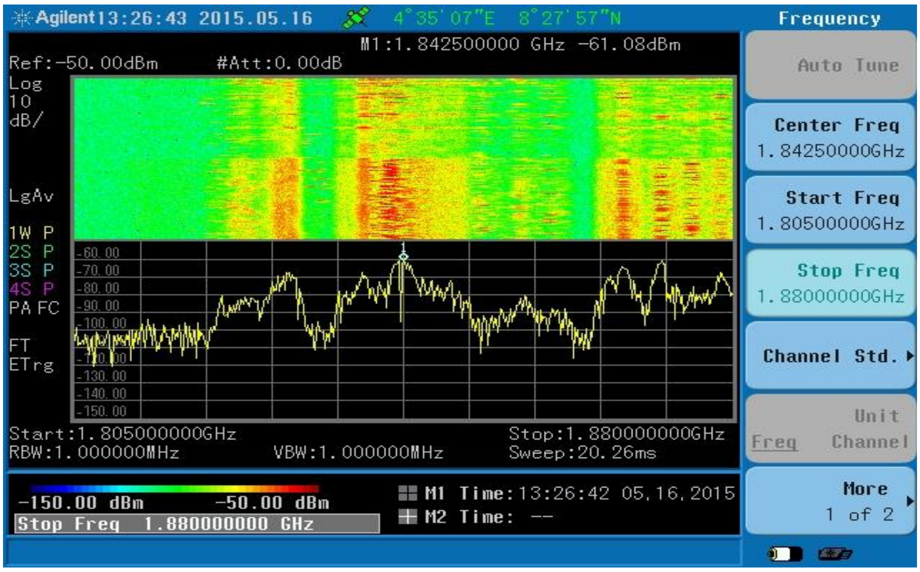


Figure 9. Spectrogram for Location 8 (Pipeline) for GSM 1800 MHz

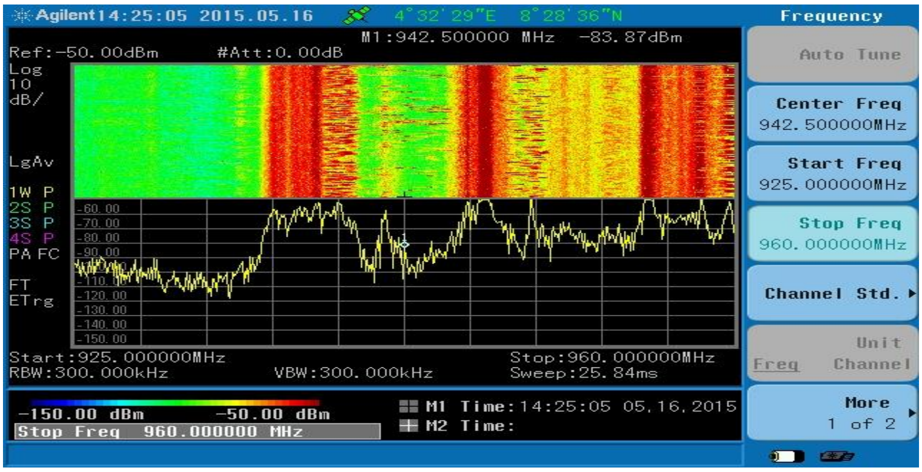


Figure 10. Spectrogram for LOC 9, Kwara Stadium for GSM 900 MHz

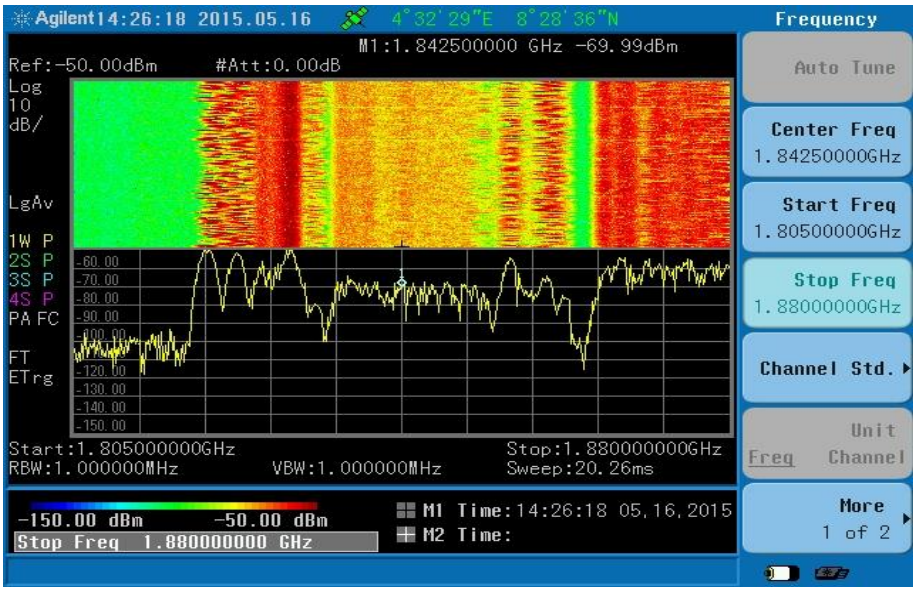


Figure 11. Spectrogram for LOC 9, Kwara Stadiumfor GSM 1800 MHz

From the findings of this work, the results collaborated with several other measurement campaigns conducted in rural and urban environments. The measurements conducted for ISM bands in [7], 0% duty cycle were obtained across all the rural areas and average occupancies of 18.56% and 22.56% in the urban locations were recorded. It is worth noting that wide disparities were observed between the measured duty cycle in rural and urban locations in [5] [15] [16] and [21]. Even though, these works are not specific to only GSM band, rather, a wide range of frequencies were considered. However, an attempt was made by authors in [9] to study this spatial variance of the duty cycle that exists in the GSM band. The work only addressed the GSM 900 bands. More so, the spatial correlation between the bands and locations are not provided. This work is therefore novel as it addressed the spatial variability of the duty cycle in both GSM 900 and 1800 MHz bands by presenting the results obtained in a spectrum measurement campaign performed over a rich diversity of measurements (i.e. urban and Rural). Furthermore, the work provided the Pearson's correlation coefficient matrix of the duty cycle across the bands and locations. The obtained results indicated that the occupancy level strongly depends on the considered location, with significant variations across the bands.

## 4. CONCLUSION

In this paper, we have examined the spatial variation of duty cycle in the GSM 900 MHz and 1800 MHz bands for specific rural and urban locations in Ilorin, Kwara State, Nigeria. The results show spatial variance in the duty cycle with average occupancies of 1.67% and 17.76% in the rural and urban locations respectively, and an overall of 10.55% in all locations for GSM 900 MHz band. For the GSM 1800 MHz band, 0.39%, 11.00% and 5.11 % were recorded in the rural, urban and overall locations respectively. Findings also show that there is very high positive correlation between rural 900 MHz and rural 1800 MHz bands, urban 900 MHz and urban 1800 MHz. However, very high but negative correlations were obtained between urban 900 MHz and rural 1800 MHz , and then between urban 1800 MHz and rural 1800 MHz. A weak and negative correlation was obtained for rural and urban 900 MHz. The correlation for rural-urban 1800 MHz was also negative but higher than 900 MHz band. Furthermore, it was found that Gaussian normal distribution can perfectly be used to represent the distribution of the received signal levels across most of the locations. Findings also indicate that higher duty cycle does not necessarily mean better signal quality and the methodology used in computing the duty cycle metric does not cater for temporal variation of the received signal strength. Therefore, it clearly shows that there is abundance of unutilised spectrum within the GSM band in the rural areas. The telecommunication regulatory commission in Nigeria should adopt useful techniques such as flexible spectrum reuse strategy to relax the regulatory bottlenecks in the regulation of the spectrum in order to maximize the scarce radio resources in the licensed bands, especially for rural network deployments.

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