Spectrum Occupancy of GSM 900 Downlink of Active GSM Operators in Ilorin Metropolis

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ABSTRACT

Spectrum measurement campaign was carried out in a highly commercial location in Ilorin, Nigeria, over the GSM 900 downlink for a week. Emphasis was placed on assessment of the spectrum allocated to the four active mobile network operators using the band link. Varying noise level ranging from 6-10dB above the noise floor was used in deciding spectral signal presence or vacancy. Signal below the threshold indicates spectral vacancy and vice versa was. The computed average spectrum occupancy is 60.22%. We inferred that about 7.46MHz spectrum was unoccupied.

Keywords: Cognitive radio, Detection threshold, Duty cycle, GSM 900, Measurement, Spectrum occupancy

iSTEAMS Proceedings Reference Format

Frederick Ojiemhende Ehiagwina, Nazmat Toyin Surajudeen-Bakinde, Nasir Faruk & Lateef Olashile Afolabi (2019): Spectrum Occupancy of GSM 900 Downlink of Active GSM Operators in Ilorin Metropolis. Proceedings of the 19th iSTEAMS Multidisciplinary Conference, The Federal Polytechnic, Offa, Kwara State, Nigeria. 7th – 9th August, 2019. Pp 135-142. www.isteams.net/offa2019 - DOI Affix - https://doi.org/ 10.22624/AIMS/iSTEAMS-2019/V19N2P15

1. INTRODUCTION

Under this fixed spectrum allocation paradigm, the spectrum is becoming a scarce resource as more and more services are demanding spectrum. In addition, unlicensed band such as the Industrial, Scientific and Medical radio bands (ISM band), which hitherto may be used by any potential wireless communication user are speedily becoming congested owing to the wide range applications using it in communication. Noticeably, a large percentage of the allocated spectrum is under-utilized (Faruk et al., 2016). Hence, there is a need to rework spectrum allocation policies of various countries of worldwide, to introduce dynamism. This will help sustain the ever-increasing wireless connections and system application cases relying on spectrum and increase spectrum efficiency. Dynamic Spectrum Assess (DSA) technique have been proposed as a viable solution to spectrum allocation inefficiencies (Akyildiz, et al., 2008). With DSA secondary user should be able to use vacant spectrum in an opportunistic manner without interfering with the licensed primary users. This demands a comprehensive understanding of spectrum usage and dynamic behaviour of primary users in a realistic scenario.

The radio environment and spectrum utilization varies according to location. As such, it is crucial that the actual behaviour of spectrum utilization in a given environment be characterised. As opined by Faruk et al. (2016), this would aid the growth and robust deployments of cognitive wireless communication systems with capacity to take full advantage of under-utilized spectrum. Therefore, the aim of this paper is to provide spectrum occupancy measurement in a busy location in Ilorin over the Global System for Mobile communication (GSM) 900 band link. Several of the spectrum occupancy measurements in the literature are based on energy detection spectrum sensing owing to its simplicity. In energy detection, cognitive radio independently has the capability to determine the presence or absence of a primary user in a spectrum fragment.

A hypothesis based model for energy detection, for a received signal $y(t)$, the transmitted signal $x(t)$ is:

$$H_0 : y(t) = w(t) \quad (1)$$

$$H_1 : y(t) = h.x(t) + w(t) \quad (2)$$

where:

H_0 and H_1 represent the hypothesis corresponding to "signal absence" and "signal presence" respectively
$w(t) =$ additive white Gaussian noise (AWGN) with zero mean and variance σ_n^2 and
$h =$ the amplitude of channel gain.

It is assumed that the noise and signal are drawn from a complex Gaussian distribution with zero mean and variance σ^2 (Molisch, Greenstein, & Shafi, 2009). Selected work dealing with the presence or absence of signal on selected spectrum across the globe are highlighted next. Melo, Arroyave, & Quijano (2018) studied the spectrum usage of frequency range between 850 – 2000MHz in Bogota, Colombia. The authors reported an average occupancy rate of 17.3%. Xue et al. (2013) carried out a 24 hours spectrum occupancy measurement over the spectrum band of 450 - 2700MHz in Beijing, China (39.9042^{0}N, 116.4074^{0}E). The spectrum analyser used is the Agilent N9030A (Agilent 2018) with a broadband omnidirectional antenna. The average spectrum occupancy duty cycle observed was 5%. Ali, Chen, & Yin (2016) examined the occupancy of GSM 900 band in Jamshoro, Pakistan. The reported occupancy rate was 30.23% - 78.07%. Al-Hourani et al. (2015) evaluated the spatial dimension of the dynamic nature of spectrum occupancy by using a measuring system attached to a moving vehicle for the range 400 – 6000 MHz for Melbourne, Australia.

Examples of the spectrum measurement exercise done in Africa include (Ayugi, Kisolo, & Ireeta, 2015; Barnes, Vuuren, & Maharaj, 2013; Bavoua, Ngono, & Ele, 2018; Faruk et al., 2016, 2017; Najashi & Feng, 2014; Popoola et al., 2016). Barnes et al. (2013), in addition to the GSM bands, covered UHF range in Pretoria, South Africa. They observed a duty cycle for the GSM bands to be of the range 40%-90%. Najashi & Feng (2014) investigated the occupancy of 700 – 2400MHz in Abuja, Nigeria. The duty cycle reported was 17% - 26%. Ayugi et al. (2015) measured occupancy level of GSM 900 and GSM 1800 in Kampala, Uganda. It was observed that spectrum duty cycle is 0.5 – 52%. Popoola et al. (2016) performed a measurement campaign to investigate the radio spectrum occupancy of 80 – 2200MHz in some selected locations (Ado-Ekiti, Akure and Ikeja) in South-Western, Nigeria. A duty cycle of 0.08% – 64.4% was observed. Faruk et al. (2016) measured the occupancy in terms of the average duty cycle of 50 – 6000 MHz for Ilorin, Nigeria.

A modified duty cycle metric was presented by introducing a space variable into the existing metrics. With the introduction of a variable energy detection threshold technique, the results indicate the average spectral occupancy duty cycle of 0.18%, and 5.08% in rural and urban locations respectively during weekdays and 1.45% on weekends for urban locations. In addition, it was shown that GSM 900 shows significant temporal variation when compared with GSM 1800. A duty cycle of 30% - 86.82% was observed in the measurement done by Bavoua et al. (2018) across the GSM bands in Yaoundé, Cameroon.

2. MATERIAL AND METHOD

Measurement Location

Spectrum field measurements in busy commercial location in Ilorin was carried out to determine spectrum occupancy of active mobile operators using GSM 900 downlink. Details of the location is shown in Table 1.

Table 1: Details of selected measurement location

Location	Category	GPS Coordinates
Post Office-GRA area	Urban	8.511^0N, 4.594^0E

The map of the measurement location is shown in Figure 1.

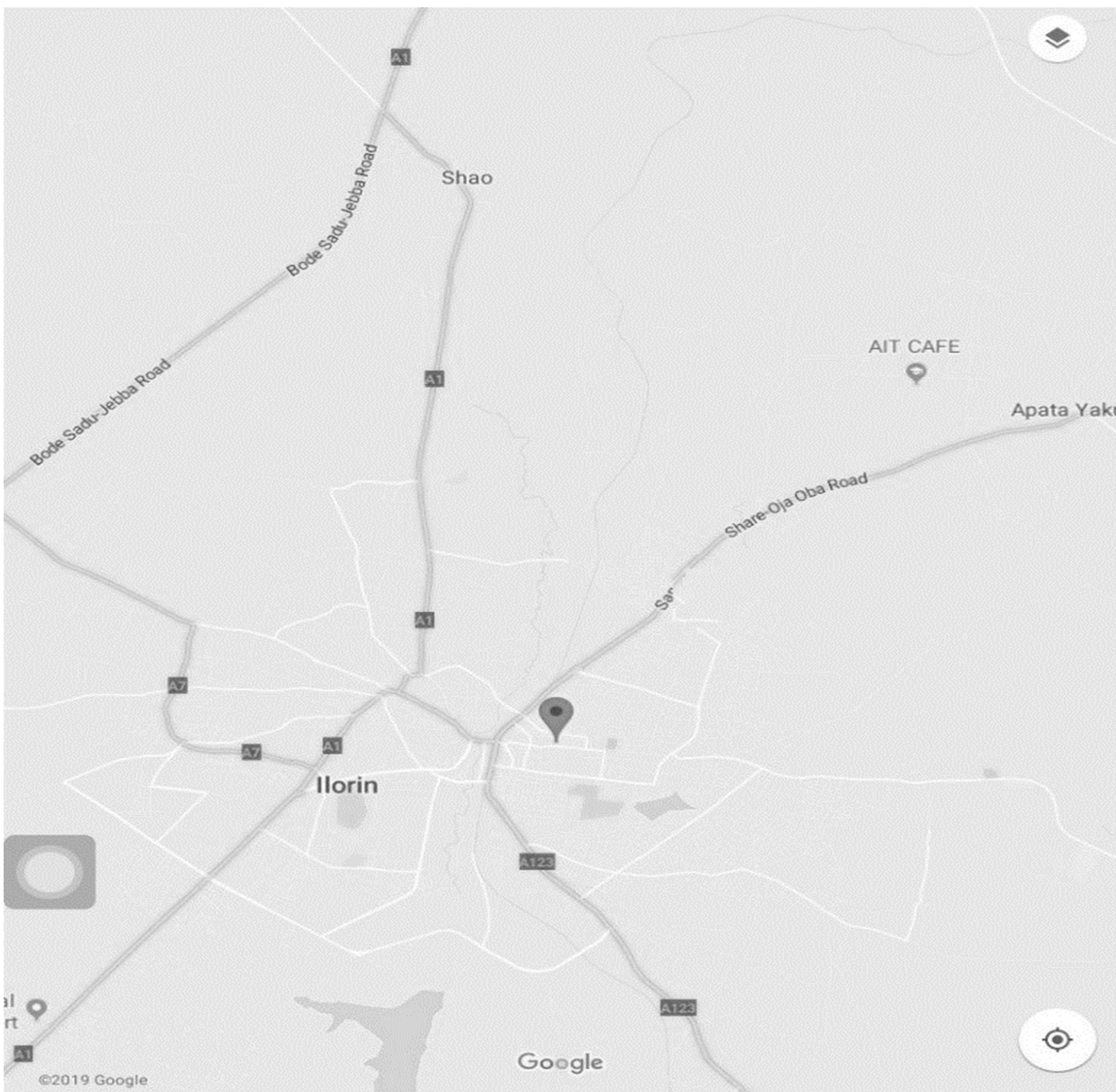


Figure 1: Map of the location for measurement

Spectrum Band
Table 2 shows the cellular wireless communication service considered in this research and its corresponding allocated spectrum band.

Table 2: Wireless services in the chosen spectrum band (885 – 1880 MHz)

Wireless Services	Allocated Band (MHz)	Bandwidth (MHz)
GSM900 Downlink (RL)	925 – 960	35

Measurement Equipment Setup
The measurement setup should be capable of sensing both weak and strong signal over the defined frequency range, hence, a sensitive spectrum analyser will be used. The experimental setup will consist of energy detector, a field strength analyser (BK PRECISION 2640) with 100 kHz – 2.0GHz frequency range, Omni directional antenna, mobile phone-based GPS and a high capacity storage device embedded within the laptop (Hewlett Packard EliteBook 840 model). The GPS enables the determination of the coordinates of each location spectrum measurement. Table 3 highlights key specifications of the BK PRECISION 2640 field strength analyser sourced from BK PRECISION 2640 user manual.

Table 3: Selected specifications of the *BK PRECISION 2640 field strength analyser*

Parameter	Value
Frequency range	100 kHz to 2.0GHz
Accuracy	±3 ppm/display: ±1.5 ppm
Resolution	3.125 Hz
Resolution bandwidth	Variable
Input impedance	50 Ω
Sweep time	Min. 500 ms

Source: BK PRECISION

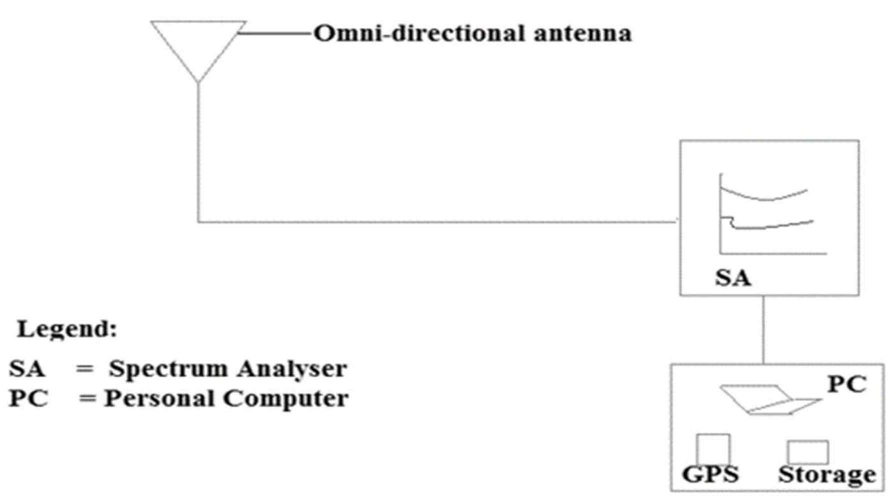


Figure 2: The measurement setup

The measurement system is based on energy detection because of its simplicity. In addition, it is preferable since much information is not previously known except the measurement power.

Frequency Bin Size, Resolution Bandwidth and Setting of Decision Threshold

The selected frequency bin size is done with consideration for the service bandwidth. Spectrum occupancy prediction is more accurate if the frequency bin size remains reasonably lower than the signal bandwidth. Frequency bin size larger than the signal bandwidth leads to overestimation of spectrum usage in the region of low PU activity. Furthermore, ability of the system to measure weak signals at the trade-off of increased measurement time is improved when the resolution bandwidth (RBW) is narrowed. This is owing to the fact that a narrower RBW increases the ability of the system to resolve signal frequency and reduces the noise floor. A 12.5 kHz RBW was used. This is a good trade-off between time required to measure indicated by the average spectrum analyser sweep time and detection capability reflected in the observed duty cycle. The duty cycle is computed using Eqn. (3)

$$Duty\,Cycle = \frac{Signal\,occupation\,period}{Total\,observation\,period} \times 100\% \quad (3)$$

Duty cycle is sensitive to the chosen decision threshold. Significantly low decision threshold results in overestimation, which is due to noise samples above the threshold. However, very high decision threshold leads to underestimation of the actual occupancy rate of the spectrum owing to misdetection of faded primary transmissions. Variable m_i-dB criteria will be used in setting the decision threshold. Here, the threshold is placed m_i-dB above the average noise level determined by a matched load placed across the SA, depending on the band. The variable m_i-dB criteria will be used since the noise variance $\sigma X(f)$ and the maximum noise level may vary from one band to another depending on the measurement setup, and as such a constant m-dB threshold over the entire frequency range being measured is not appropriate. The decision threshold λ_k in dB is expressed in Eqn. (4).

$$\lambda_k = \mu X(f) + m_i \quad (4)$$

$\mu X(f)$ is the average noise level.

3. RESULT AND DISCUSSION

In Nigeria there are five (5) Public Land Mobile Network areas belonging to Airtel Nigeria, EMTS (Etisalat) now 9Mobile, Globacom, MTN Nigeria and the defunct M-Tel (now ntel) operating in the GSM band - Down Link (DL). Their spectrum assignments in GSM 900 is shown in Table 4.

Table 4: Mobile network operators and their spectrum assignment in GSM 900 DL

Mobile Network Operators	GSM900 DL (MHz)
9Mobile	935 - 940
Ntel	940 - 945
Globacom	945 - 950
MTN	950 - 955
Airtel	955 - 960

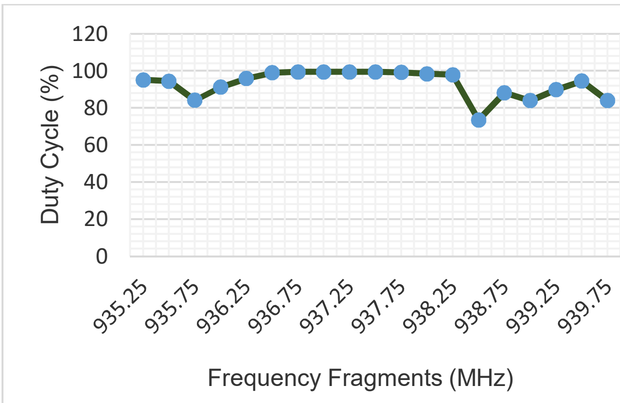


Figure 4: 9Mobile spectrum occupancy

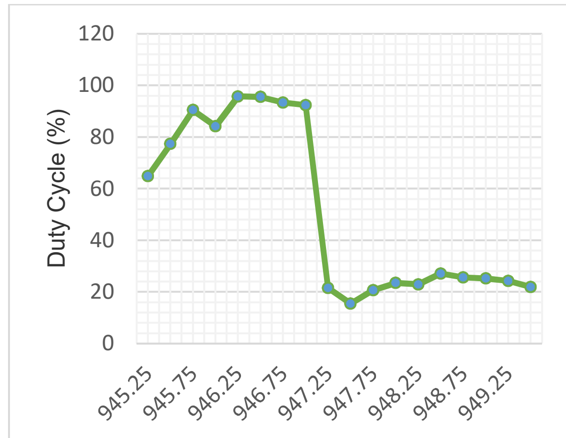
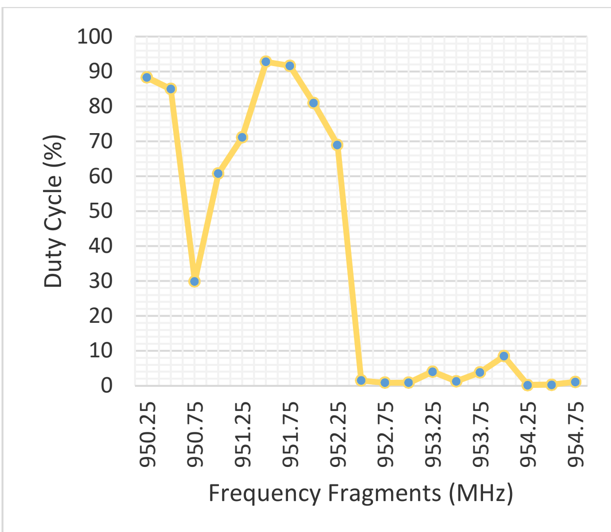


Figure 5: Globacom spectrum occupancy



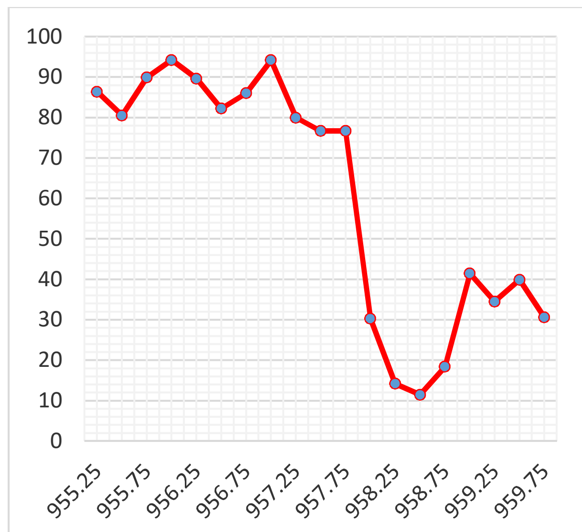


Figure 6: MTN spectrum occupancy

Figure 7: AIRTEL spectrum occupancy

It was observed that AIRTEL has spectrum occupancy of 60.93%, MTN has an occupancy of 36.46%, Globacom has an occupancy of 50.48% and 9mobile has a spectrum occupancy of 93.02%. The charts shown in Figures 4 – 7 indicate a fairly stable occupancy for 9mobile and low occupancy for the second half of the spectrum allocated to the other three mobile network operators.

In Table 5 an estimation of the occupied spectrum bandwidth is presented.

Table 5: Mobile network operators and their spectrum assignment in GSM 900 DL

Mobile Network Operators	Unoccupied Spectrum in GSM900 DL (MHz)
9Mobile	0.349
Ntel	Not active in Ilorin
Globacom	2.476
MTN	3.177
Airtel	1.954
Total Unoccupied Spectrum	7.956

4. CONCLUSION

In this works spectrum occupancy of the GSM 900 downlink was carried out in a selected location in Ilorin. 9mobile has the highest spectrum occupancy of 93.02%. The average occupancy was determined to be 60.22%. The implication of this is that of the 20 MHz allocated to the four studied mobile network operator in GSM 900 DL, about 7.96MHz is occupied on the average. This occupied spectrum could be used by a cognitive user in an opportunistic way. In addition, operators could generate additional revenues by sub-leasing out this vacant spectrum. Future work should design a robust pricing and incentive scheme that could assist regulators and operators in this regard. Also, other bands and links should be studied on a continual basis to determine their occupancy level. We recommend that cognitive hardware capable of exploiting sensed spectrum vacancies should be research and developed.

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