SPECTRUM OCCUPANCY MEASUREMENTS IN NIGERIA: RESULTS AND ANALYSIS

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ABSTRACT

Cognitive radio paradigm has been identified as the solution to spectrum underutilization. It promises to change the face of spectrum management from planning, allocation and subsequently and most importantly utilization. The present command and control approach in allocating spectrum has been found to be ineffective. This inefficiency has lead to a perceived spectrum scarcity. Spectrum occupancy measurements have disputed this fact; through these measurements it has been found that the spectrum is actually underutilized. Thorough understanding of the allocated spectrum will go a long way towards the successful deployment of cognitive radio paradigm. Currently, several spectrum occupancy measurements have been performed all over the world to ascertain the true behaviour of the allocated spectrum. In this paper, a spectrum occupancy measurement performed in Nigeria is presented. This has become necessary because spectrum occupancy measurement performed in a certain location cannot be extended to other locations. From the results obtained, it has been found there is ample spectrum available. Correlation analyses performed also indicate that spectrum occupancy depends on both time and location. This work will go a long way in the deployment of cognitive radio technology in Nigeria.

Keywords: Cognitive radio, spectrum, spectrum occupancy measurement, Nigeria.

1. INTRODUCTION

The last two decades have witnessed a tremendous growth in the area of wireless communication. Several new standards have been developed over the years which have increased the demand for spectrum available. Initially it has been believed that the spectrum shortage is due to the recent advancement in wireless communication especially in cellular communication. Recent research has however found out that contrary to this belief the spectrum is mostly underutilized with several spectrum holes discovered. It has become necessary then to review the current command and control approach to spectrum allocation which is both rigid and inflexible to a more flexible one where the spectrum could be shared among users [1]. This concept constitutes the underlying principle of cognitive radio where a primary user (licensed user) shares the spectrum opportunistically with a secondary user (unlicensed user) with the premise that the secondary user doesn't cause interference to the primary user [2]. The concept of Cognitive radio was first introduced by Mitola [3] in 1999. He described cognitive radio as a smart radio that has a full understanding of its environment and can also adapt its operating parameters to adapt to changes in the environment. The importance of spectrum occupancy measurements cannot be underestimated. The knowledge of the utilization level of the spectrum bands will help researchers to conceive (devise) spectrum models that could be used to predict future utilization. It could also help policy makers in determining which bands have low occupancy: this will go a long way in determining the bands that are suitable for dynamic spectrum access. Spectrum usage is dependent on location, time, measurement conditions, and equipment [4]. While spectrum monitoring tends to provide detailed information on conformity with laid down rules pertaining spectrum usage which a spectrum planner uses to ascertain the level of compliance and also to confirm the effectiveness of current planning system, spectrum measurements on the other hand tend to quantify the performance of the measuring band. In [5], Kishor Patil et al. conducted a spectrum occupancy measurements in the frequency band from 700MHz to 2700MHz in an outdoor scenario in suburban Mumbai; it was found that the spectrum occupancy of the entire band to be roughly 6.62%. In [6], a measurement campaign was performed in

Guangdong province in china which also showed a low occupancy. Shared Spectrum Company has performed many measurement campaigns in several American cities which also showed low spectrum occupancy [7]. De Francisco, R et al. and Miguel Lopez-Benitez et al. performed spectrum occupancy measurement in Netherlands and Spain respectively. The results were similar to what was obtained in other campaigns [8],[9]. Other measurements conducted [10-12] and [19-23] also proved that the spectrum utilization level is low across the bands investigated.

The deregulation of the telecommunication sector in Nigeria in 2001 has lead to a remarkable growth in the wireless communication services sector especially cellular communication. With the launch of the country's first satellite, the Nigersat-1 which is basically a remote sensing satellite, the government signalled its intention to develop this vital area of the economy. NigComSat-1R, a communication satellite, was re-launched in 2011 after earlier attempts in 2007 failed. The satellite was launched in partnership with China Great Wall Industry Corporation with the aim of further improving the communication infrastructure. Spectrum scarcity has been a dilemma recently; African countries suffer more in this regard because of their heavy reliance on wireless communication services due to non-availability of other vital infrastructure such as copper and fibre optic networks. Therefore it could be said that the transmission channel is not readily available, thus the overcrowded nature of the spectrum allocated for broadband communication. In Nigeria's case, the population of over 150 million with over 100 million active lines has affected the network quality of these services. To increase quality, capacity must be increased and to increase capacity there must be more spectra. Even though other services could be considered, the affordability across users must be taken into consideration as most users won't be able to afford expensive services. These factors and others lead to the African region headed by Nigeria to demand for further spectrum allocation during the World Radio Conference 2012. They argued that the allocation will improve the quality of broadband services and also increase mobile internet penetration amongst the populace. Currently, the ITU has granted the 700 MHz for efficient delivery of broadband services for this region. It has therefore become extremely important to study the spectrum utilization, behaviour, and analyze the data obtained from these measurements in order to formulate and plan for the future due to the uniqueness of Nigeria's case. The motivation for this work can be summarized into two; to provide an insight into the spectrum occupancy in Nigeria for regulatory authorities and researchers alike as this the first of such measurements pertaining Nigeria that is available in literature. Secondly, to provide the data necessary to fully understand and analyze the nature of spectrum usage in Nigeria this will ultimately provide the policy makers with valuable information for making informed decisions. Therefore, the main contribution of this work is providing the first spectrum occupancy in Nigeria that will provide a platform for future deployment of cognitive radio paradigm. Furthermore, a contribution towards understanding the spectrum utilization pattern is presented. It is hoped that these contributions will provide an insight into the spectrum usage as far as Nigeria is concerned.

In this paper, the results of a spectrum occupancy measurement conducted in Nigeria are presented; the utilization level measured in terms of occupancy is given with bands experiencing low frequency presented. Correlation analysis results are presented to determine the effect of time and location as it affects the utilization behaviour of the spectrum in two distinct location. From the correlation results, it has been established that spectrum utilization depends on both time and location. The rest o the paper is organized as follows; Section two describes the spectrum occupancy measurement setup, location and parameters used. In section 3 the results of the spectrum occupancy measurements are given while section four covers the correlation analysis. Finally conclusion is given in section five.

2 Spectrum Occupancy Measurements

2.1 Measurement Setup

The measurement setup employed in this work is depicted in figure 1. It consists of an Aaronia AG HF-6060 V4 spectrum analyzer with a range of 10MHz-6GHz, an Aaronia AG OmniLOG 90200 antenna with a range of 700MHz to 2.5GHz, a laptop system that is connected to the spectrum analyzer via a USB cable, and an MCS software specially designed to run on Aaronia AG spectrum analyzers. The MCS software helps in storing the power level experienced by the spectrum analyzer in real time using a .csv format. Further processing is done using a database processing software before the data is fed to MATLAB for further processing and analysis.

Fig. 1. Setup used for Spectrum Occupancy measurement

2.2 Location

The measurements were conducted in two different cities. One being Abuja the capital city of Nigeria located at $9°4'0''N, 7°29'0''E$ and the other is Katsina City located in the northern part of the country close to Niger republic located at $12°59'0''N, 7°36'0''E$. The measurements were both conducted indoors in predominantly residential areas. The measurements were taken from 9 am to 9 pm a duration of roughly 12 hours. The spectrum analyzer settings employed in this work are given in the table 1 below:

Table 1. Spectrum Analyzer Parameters used in conducting the measurement

PARAMETER	VALUE
Span	200MHz/300 MHz
Timing	500 ms
Resolution(samples)	51
Bandwidth Filter	200 KHz
Video Filter	200KHz

The frequency span used for this work was selected based on the services and also the limitation of the device being used. After several trials, it was found out that the Aaronia spectrum analyzer cannot record the data accurately when the span is over 300 MHz. We therefore restricted our span to 300 MHz and in some cases 200 MHz because of the services being used in those bands. The Bandwidth filter helps in determining the value of the noise floor as well distinguishing two very similar signals by resolving them into two separate peaks, in essence RBW allows for differentiating two similar signals. The video bandwidth differentiates between two different power levels. This is because a narrower VBW will remove noise in the detector output. This filter is used to "smooth" the display by removing noise from the envelope. The general convention here is to select an RBW value that is greater or equal to VBW. Moreover, from an application point of view spectrum white spaces of few tens of kHz are not interesting for opportunistic use and the rather coarse resolution bandwidth of 200 kHz represents a good compromise [22]. The timing parameter was set to 500 ms which means it takes 16 seconds to conduct a sweep, which in turn translates to 2,700 data points over a 12 hour period.

In energy detection scheme which is employed by spectrum analyzer, no prior information about the signal is known prior to detection. In determining whether a channel is busy or free, the power level detected by the spectrum analyzer for a given time is compared to a predetermined threshold to make the decision [4]. It is therefore very important to accurately determine the threshold as setting the threshold too high will lead to under-estimation of the occupancy status of the band under question while setting the threshold too low will lead to over-estimation; both these cases will ultimately lead to interference amongst users since the decision made is inaccurate. In this measurement, two methods were used to determine the threshold: one way is by removing the antenna and not replacing it with anything. The reading obtained is the noise floor value required. Secondly, a 50 ohm resistor can be attached at the point where the antenna was previously located and the readings taken. Both of these methods have been previously used in previous measurements [13]. Depending on the band being measured, a threshold of -86 to -76 dBm was used.

3 Spectrum Occupancy Results

This section presents the results of the measurements taken during the campaign. Plots of power against frequency and waterfall plots are used to visualize the results. We then present the occupancy results of each and considered in order to quantify the bands with low utilization level. A table of the most popular services allocation in Nigeria is presented in table 2 below.

Table 2. Spectrum Allocation Table for some services in Nigeria

BAND	FREQUENCY RANGE	USAGE AND PLAN
800 MHz	790 – 806 MHz	Trunk Radio Services
900 MHz	890-960 MHz	GSM
1 GHz	1.35-1.525 GHz,1.579-1.772 GHz 1.805-1.91GHz,1.96-1.99GHz	Rural Telecoms, GSM, Oil coy. Satellite broadcast, radio navigation services.
2 GHz	1.99-2.11 GHz,2.2-2.285 GHz, 2.305-2.32 GHz,2.345-2.36 GHz, 2.4- 2.5GHz	3G mobiles ,wireless local loop, satellite up/downlink, scientific, industrial and medical applications

For the purpose of this work, 700 MHz to 2400 MHz range was considered. It was divided into seven bands due to the limitation of the device used for conducting the measurements and also based on the services using these bands. Table 3 shows these bands.

Table 3: The bands considered during the measurement

BLOCK	FREQUENCY RANGE(MHz)
1	700-1000
2	1000-1297.5
3	1297.5-1500
4	1500-1700
5	1700-1997
6	1997-2200
7	2200-2400

A power level versus frequency figures with a waterfall figure are used to visualize the energy utilization over a given frequency band. In the power level figures, the frequencies with higher utilization are characterized by high power levels while those with low usage are characterized by lower power levels. Furthermore, the waterfall figures help to visualize the power levels experienced in a given band over a period time with blue colour indicating no usage and green indicating a fully utilized band. The main difference between the two figures is that while the power versus frequency figures gives the instantaneous power usage over a given band the waterfall figures provide information on the said usage over a given period of time. The first band considered was the 700-1000MHz. It comprises the 800MHz band used for trunk radio services, emergency services, CDMA (fixed), 900 MHz for GSM and also the 470-960 MHz for analogue television broadcasting [14]. In the VHF band there are 12 channels where as the UHF band consists of 49 channels making a total of 61 channels [15]. This band has the highest utilization level experienced at 26% due to the activities of the analogue broadcasting (part of it to be precise) GSM operations and the radio trunk services as is evident from figure 2 and figure 3. CDMA technology employs the use of spread spectrum whereby the signal power is very low almost the same with noise power. This makes the signal difficult to detect by the spectrum analyzer. The utilization level could be much more than the obtained value due to this factor.

The 1000- 1500 MHz band is mostly used for microwave point to point communication (1350-1550MHz), government agencies and oil companies in the Niger delta region and Lagos [16].The 1000-1300 MHz and 1300-1500 MHz with a utilization level of 2.13% and 1.85% respectively. These are depicted using power level versus frequency figure for 1300-1500 MHz in figure 4 and the waterfall figure for 1300-1500 MHz in figure 5 which are among the bands with the lowest utilization level. Apart from microwave point to point transmission observed around 1350-1450MHz; there is virtually no activity at all.

Above 1.5 GHz, majority of the utilization can be observed in the 3G mobile standards. With a utilization level of around 25.1% it has one of the highest utilization level amongst the bands considered for this work. In Nigeria, there are currently five mobile companies delivering 3G mobile services: MTN, Globacom, Airtel, Etisalat and Starcomms [17]. Networks employing UMTS use WCDMA technology as stated above, the spread spectrum nature of the signals whereby the signals are modulated over a wide bandwidth thus making them to have a noise-like character due to the very low transmission power and hence difficult to detect. This makes it difficult for the spectrum analyzer to determine such signals. Similarly, since the measurements were conducted indoors, the ability of the antenna to receive signals might be hindered. Above 2.42 GHz, with 17% utilization, the ISM band shows considerable utilization but it could also provide some opportunity for secondary usage. As the measurement was done indoors it was able to detect much of the signals due to the short nature of signals in this band. Some activity on the satellite uplink and downlink bands were also detected at a frequency of 2.305-2.32 MHz and 2.335-2.36 MHz.

Table 4: Summary of Spectrum Occupancy

BLOCK	FREQUENCY RANGE(MHz)	DUTY CYCLE
1	700-1000	26%
2	1000-1297.5	2.13%
3	1297.5-1500	1.85%
4	1500-1700	12.7%
5	1700-1997	25.56%
6	1997-2200	0.45%
7	2200-2400	17.42%

Fig. 2. Power level in dBm versus frequency (700-1000 MHz)

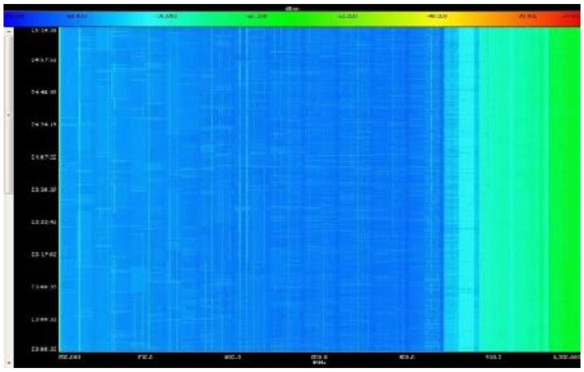

Fig. 3. Waterfall for700-1000 MHz

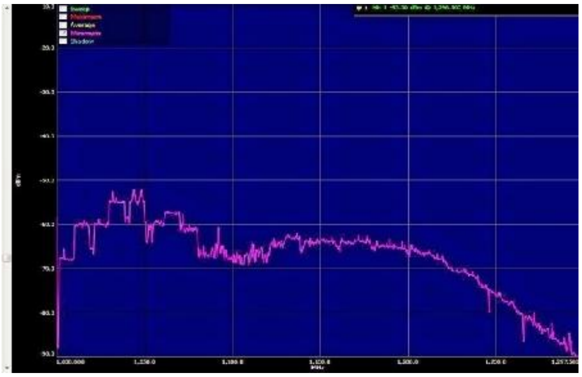

Fig. 4. Power level in dBm versus frequency (1000-1300 MHz)

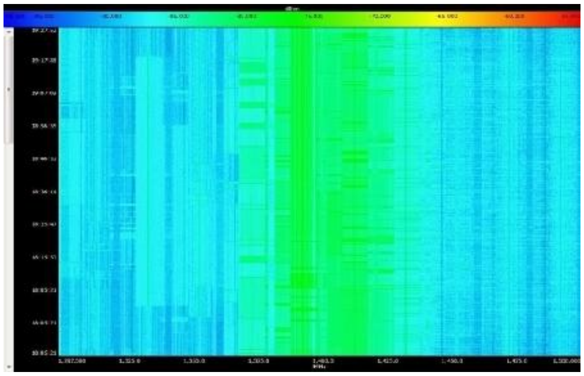

Fig. 5. Waterfall for 1300-1500 MHz

4 Correlation Analysis

4.1 Hourly Comparison

Understanding the level of utilization over 24 hour duration is the primary aim of this section. The data for this analysis was obtained from a spectrum occupancy measurement conducted in July 2012 from 700-2400 MHz. Hourly occupancy is used to determine which channel's occupancy remains constant and which doesn't. To achieve this goal, mean and standard deviation of these channels over one hour periods were calculated and plots presented. Channels with a higher standard deviation indicate channels with highly unpredictable occupancy with a moderate value indicating less unpredictability and low values indicating predictable occupancy.

For this analysis, bands containing the three most utilized bands i.e. TV broadcasting, 2G cellular band and the 3G cellular bands were investigated. The TV broadcasting band was found to be transmitting during the whole day with the occupancy being highly unpredictable. However during the night, especially after 00:00, there seems to be fewer transmissions with the occupancy being predictable. This observation is in tune with the normal operating manner of such bands as most of the TV stations switch off their transmission after 00:00. The 2G and 3G cellular bands indicate a random occupancy from being highly unpredictable during the day time to being moderately predictable at night. This pattern is also understandable with more people utilizing the bands during the day and less people using the services at night. In summary, it can be said that unpredictable occupancy is mostly experienced during the day while occupancy with a predictable nature found during the night. Similarly, high utilization is found during the day time with lower utilization values experienced in the night especially in the TV broadcasting band.

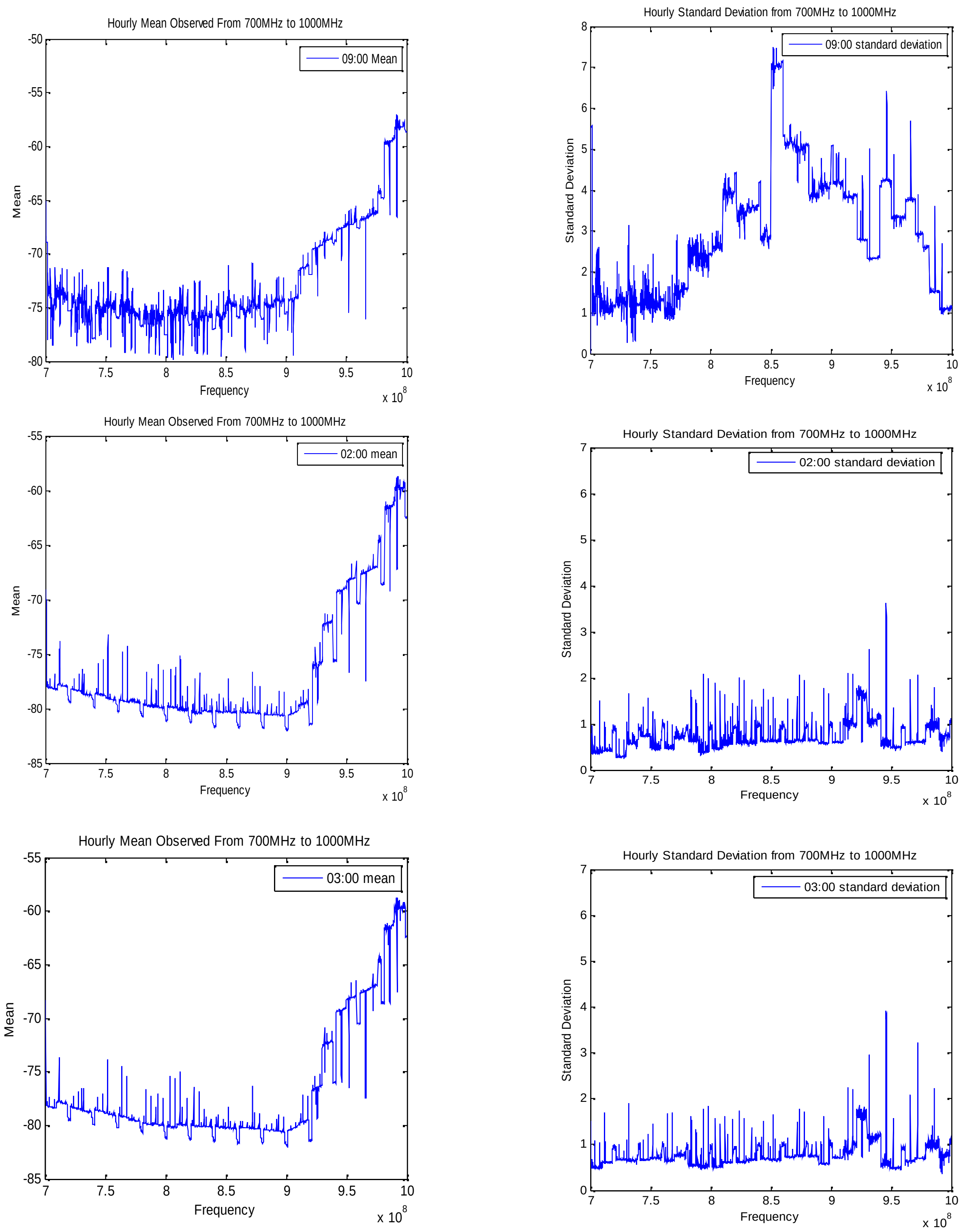

Fig. 6. Plots indicating hourly variations in Spectrum Usage

4.2 Spectral Correlation

The need to examine the correlation among frequency channels is paramount. The correlation should be over a longer period of time due to the unpredictable nature of usage as this will provide a calculated insight into the actual correlation of the channels in question. In this section we take a look at correlation between channels in the same service and also those in adjacent services. The need for this stems from the fact that cognitive radios would probably use some form of bundling mechanism by combining numerous frequency channels during transmission due to the short nature of most of the idle channels (lasting for less than 2 timeslots in most cases).

For this analysis, two commonly used spectrum correlation metrics used in [6, 18] are applied. One is defined by two random variables and the other is for measuring the mutual dependence of the two random variables [18]. The first metric also known as the "Pearson's correlation" is obtained by dividing the covariance of the two variables by the product of their standard deviations. The correlation coefficient $\rho(x,y)$ is given as:

$$\rho(x,y) = \frac{\operatorname{cov}(X,Y)}{\sigma_x \sigma_y} = \frac{E((X-\mu_x)(X-\mu_y))}{\sigma_x \sigma_y}$$

where μ_X *and* μ_Y are the mean, σ_X *and* σ_Y are the standard deviations of the random variables, E is the expected value parameter and cov is the covariance operator. The correlation takes a value between -1 to 1 with -1 indicating there is no correlation whatsoever amongst the variables and 1 indicating perfect correlation. Values in between indicate some degree of correlation.

The second metric for measuring the mutual information of two discrete random variables X *and* Y is define as

$$I(X;Y) = \sum_{y \in Y} \sum_{x \in X} p(x,y) \log\left(\frac{p(x,y)}{p(x), p(y)}\right)$$

where $p(x,y)$ is the joint probability function of the variables X *and* Y and $p(x)$ *and* $p(y)$ are the marginal probability functions of X *and* Y respectively. The value of this metric ranges from 0 to 1, with 0 indicating that the variables are independent and 1 indicating otherwise.

For the purpose of this analysis, an hour long data from five channels were randomly selected and processed. From the results obtained, a correlation coefficient of about 0.5 was realized amongst channels in the same service. It should be noted that some of channels used especially in the cellular bands are idle during the whole time because they serve as band gaps which are used to avoid interference amongst services adjacent to each other.

Table 5: Spectral Correlation amongst services considered

	Broadcasting	**2G Uplink**	**2G Downlink**	**3G Uplink**	**3G Downlink**
Broadcasting	0.471				
2G Uplink	0.085	0.500			
2G Downlink	0.419	0.098	0.485		
3G Uplink	0.384	0.427	0.421	0.500	
3G Downlink	0.428	0.497	0.491	0.332	0.406

From the results obtained from the spectral correlation analysis, it can be seen that the average correlation coefficients are around approximately 0.5 in all cases considered. This implies a degree of independence in the spectrum utilization patterns across the services. Factors that might probably contribute/affect these results include:

1. The data used might include channels that are completely busy or completely idle. Channels used as band gaps belong to this category and can influence the results.
2. Spectrum usage at different places might also influence the results. This should be expected as spectrum utilization from two locations can never be the same [4].
3. The difference between the uplink and downlink correlation results might be attributed to the fact that the base station is continuously transmitting information to the mobile users which is not the case with the uplink band. This behavioral difference might be linked to the low correlation experienced amongst these bands.

These results notwithstanding, the assumption in [4] that spectrum utilization depends on time, location, measurement conditions and device could be true to a certain degree. The spectral correlation analysis has shown that the channels are not correlated even among those in the same bands. This conforms to [18] where they found that channels are mostly independent in their spectrum usage patterns. This also contradicts [6] where they found high correlation amongst the channels evaluated.

4.3 Temporal Correlation

For this analysis, occupancy results from Katsina town and Abuja city are compared and correlation analysis performed amongst the services common to both cities. The 2G uplink, 2G downlink and the broadcasting bands were considered;. Data from 2G uplink, 2G downlink, and broadcasting bands from the two locations were correlated. The choice of these services is due to the fact that they are common to both places as at the time of conducting this work. An hour long data from these data subsets is obtained, these are then correlated against the same services from the other location.. For example data from 2G uplink in Abuja was correlated with data from 2G in Katsina and so on. Results indicates that there is little or no correlation amongst the services The correlation results were found to be 0.1023, 0.4999, and 0.2303 for 2G uplink, 2G downlink, and broadcasting band respectively. These results show little correlation amongst the services in the two locations considered and are in tune with the generally known fact that spectrum utilization is dependent on location

5 Conclusion

In this paper, the results of the first spectrum occupancy measurement performed in Nigeria, in primarily two cities one being the capital city of Nigeria: Abuja while the other is a city in the northern part of the country is presented. Results obtained indicate low occupancy levels across the bands considered with 700-1000 MHz having the highest utilization level with 26% while the 2000-2200 MHz has the lowest occupancy with 0.45%. These results are in tune with most measurements performed around the globe. As this is the first of such measurements from Nigeria available in literature, it will be difficult to compare with other works in the that context Furthermore correlation analysis performed also buttressed the fact that spectrum utilization and behaviour depends on both time and location as indicated by the results of the analysis.

The importance of this work cannot be overemphasized especially in the Nigerian context. Recent allocation of the 700 MHz for mobile broadband communication by the International Telecommunication Union ITU to the African Region to boast broadband internet penetration has made it paramount to have a clear picture of the spectrum usage and its behavior. This will go a long way in helping policy makers to make informed decisions on the use of spectrum.

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