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Review of Spectrum Occupancy Measurements in the Context of Cognitive Radio

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Abstract
Presently, there is a progressive growth in the proportion of internet users as well as deployment of data intensive applications which has led to higher demand for bandwidth on the usable spectrum space for the unlicensed and licensed frequency bands. Spectrum is a scarce and limited resource, inefficiencies in the management of spectrum has resulted to a recent and unique communication standard for exploiting the current licensed spectrum in an opportunistic manner. Cognitive Radio (CR) has proved to be the solution to this seeming highly demanded spectrum. Several studies have been conducted on spectrum occupancy across the world in order to observe and determine the bands that have been underutilized so as to make room for the new technological emergences such as CR. This review shows that from previous works done, there is a research gap in the spectrum measurement work for TV band and specifically the VHF band in Nigeria.

Keywords: *Cognitive Radio, Primary Users (PU), Secondary Users (SU), IoT.*

1. Introduction

Cognitive Radio has attracted so much attention because the spectrum is perceived to have been over crowded. Of late, there is an upsurge in the need for spectrum, due to the emergence of recent communication technologies and services such as (Internet of Things) IoT and 5G technologies (Li *et al.,* 2019; Hamdaoui *et al.,* 2018; Sharma *et al.,* 2018). The static allocation of frequency spectrum to network users is the reason for this. It is important to ensure spectrum access in these recent technologies and networks including device-to-device and drones enabled systems (Marota *et al.,* 2018; Shen *et al.,* 2019).

In the current policy on radio spectrum allocation, users are assigned licenses for a particular communication services and technologies. Only licensed users have permission to occupy a particular spectrum allocated to them. Unlicensed users are strictly prevented from accessing the spectrum even when they are unoccupied or vacant by the primary users (Saladhine *et al.,* 2017)

Federal Communication Commission (FCC) is the regulatory body in the USA while Nigerian Communication Commission (NCC) is responsible for communication rules and policies and also controls the usage of the limited radio resource spectrum. In the USA, previous studies revealed that spectrum occupancy is between 15 to 85% in the static allocation policy (Saladhine, 2017). According to Manesh *et al.,* (2017), measurements by FCC revealed that, while some channels are heavily used others have low usage.

Cognitive Radio is a radio that is cognizant of its spectral environment and can change operating parameters to enable seamless communication. Such radios are able to function in a wide frequency band range. When a licensed Primary User (PU) is absent, cognitive radio can opportunistically use its frequency and immediately vacate at the emergence of the licensed primary user. In this manner, the cognitive radio does not cause interference with the PU.

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Mitola (1999), was the first proponent of Cognitive Radio which requires that free and available frequency bands are already known. Hence, a holistic analysis and investigation of current spectrum occupancy in a particular geographical location is essential. This study is a survey of various spectrum occupancy measurements carried out around the world.

2. Related Works

Spectrum occupancy campaign can be said to be an empirical procedure for data collection done for a precise purpose which can be indoor or outdoor. The purpose of spectrum measurement campaigns is to get spectral samples on selected frequency bands for example; cellular bands or TV bands (Elton *et al.,* 2018). Previous works done, compute the proportion of spectral occupancy for different frequencies, time and location, paid attention to a range of frequency bands and some for particular bands allocated for specific services. In general, the results of these works reveals that spectrum utilization is low and opportunistic access to spectrum is being suggested (Arista *et al.*, 2018). However, spectrum occupancy results for a particular location may not be a representation for another location.

In literatures, measurement campaigns were done under different regulatory bodies, scenarios and with different equipment. There is therefore, the need for thorough comparative studies. Most studies focused on spectrum occupancy. For instance, Han *et al.* (2010) reported spectral measurement for TV band done in Chengdu, China with results revealing free spectrum bands which are available for unlicensed devices. Investigation into the prospects of the use of TV white space spectrum in large cities based on time and location in Malaysia was done by Rahim *et al.* (2014). The work gathered data from eight cities in Malaysia on the signal strength and spectrum occupancy level.

Campaigns on spectrum measurement were carried out in Spain (López-Benitez *et al.,* 2009), New Zealand (Chiang *et al.*, 2007), Germany (Wellens *et al.*, 2007), Singapore (Islam *et al.*, 2008) and also in South Africa (Barnes *et al.,* 2013). The results of such surveys are essential for the deployment of CR technology. However, more campaigns may be carried out in several other geographical locations in order to justify the need for CR. For example, spectrum measurement campaign carried out by López-Benitez *et al.* (2009), covers a frequency range of 75 – 7000MHz in Barcelona, Spain specifically for both sub-urban and urban areas and covers both indoors and outdoors settings. Analysis of the measurement was done with a view of determining the spectrum occupancy and comparison was done also to the approved spectrum regulation of government agency in Spain. Results obtained reveal the presence of a large amount of spectrum usable for the future Cognitive Radio devices.

Similarly, the work of Chiang *et al.* (2007) discusses the spectrum measurement campaign for the range of frequencies 806-2750MHz in the metropolis of Auckland in New Zealand. The study set to identify spectral holes for the usage of secondary devices. Statistical results in the form of amplitude probability distribution, noise distribution and spectrum occupancy rate as a proportion of time were presented. Result reveals that about 6.2% on the average of the actual spectral occupancy in the band is used.

Likewise comparative studies have been undertaken for different locations and at different bands. Such studies include the synchronous spectrum occupancy measurement done in seven European cities for a period of 2 days by Palaios *et al.* (2012). The aim of the work was to harmonise measurement settings and equipment with a view of comparing data obtained. From the results, the effect of location is strong on the measured power spectral density. Kliks *et al.*, (2013) also compared the measurement done in Spain and Poland so as to quantify spectral occupancy existing in various bands. Results show a large proportion of unused spectrum, with average spectrum occupancy of 22% in Barcelona and 27% in Poznan.

Lazaridis *et al.* (2014) presented results for the measurement of TV spectrum band (UHF) and the level of field strength in Thessalonika (Greece) as well as Skopje (Macedonia) revealing availability of opportunistic secondary spectrum access to a major part of the spectrum. In Beijing, China both fixed and mobile based spectrum measurement has been performed with a focus on the whole TV band by analyzing various parameters such as frequency, time, space domain and TV standards (Chen *et al.,* 2014). Faruk *et al.* (2019) did a study on spatial variabity of duty cycle within the cellular band. In this work, measurements were taken for nine locations with four out of the nine locations being in the city while the remaining five locations are in the remote areas and comparison was made on measurements taken. The results concluded that there is a positive correlation between the GSM900 and GSM 1800. However, the work was limited to the cellular band and did not consider or pay special attention to the VHF band.

Spectrum occupancy measurement was done in three places of the Kanto area in Japan by Contreras *et al.* (2011). Analysis of data gathered was done aiming at identifying the white space in TV band that is suitable for use by secondary users. Result shows spectrum occupancy in TV bands is 13.9%. Hoyhtya *et al.* (2015) did a survey on spectrum occupancy measurement by comparing metrics, measurement targets and equipment used. From their findings, focused and well-designed campaigns are better than universal ones. This is because a simple and generalized form of spectral occupancy value may lead to false conclusion. Although many studies on measurement of spectrum occupancy were done in various places to determine the total rate of spectrum utilization, but little effort has been made specifically on measurement and analysis of VHF band and on the sub band within the VHF.

An outdoor spectrum measurement was conducted by Wellens *et al.* (2007) in Aachen Germany and observed that the band for Unlicensed National Information Infrastructure (U-NII) is mostly vacant reason being that the commonly used home networks are 2.4 GHz and 5 GHz WiFi. Results of spectrum measurement conducted in Chicago and Finland by Do *et al.* (2004) reveals that the proportion of spectral occupancy in the U-NII band is less than 5%.

Biggs *et al.* (2004) & Ellingson (2005) also carried out measurements for frequency range of 20-3000MHz in four locations, for one week. The data storage, data analyses and the free spectra (white spaces) was determined. Comparison of the results of the four locations was done and an investigation of the fitness of the occupancy statistics to the better distribution was done. It was discovered that the frequency bands available can be used for CR.

A multiple spectrum occupancy survey was performed by Palaios *et al.* (2012) in various locations in London for a period of one week over a frequency range of 75-3000MHz. Temporary measurement systems were established in areas like Airport, streets and shopping centers. Correlation study was performed among the measurement points in the context of time, space and frequency domain. The approach used in this study shows that there is comprehensive information on spectrum use than the typical single-location campaigns.

Spectrum measurement surveys were done in eleven European countries by Van de Beek *et al.* (2012) focusing on the UHF TV band (470-790MHz). The reason for the survey is to identify the white spaces in the TV band and the results were compared with another survey done in America. A comparison of spectrum measurement study was done by Kliks *et al.* (2013) in Spain and Poland. The average ranges of occupancy are 22% and 27% for Spain and Poland respectively.

A two-day measurement survey was done in China covering a range of frequencies of 440-2700MHz by Xue *et al.* (2013). The result indicates that the TV UHF band and the GSM900 bands were heavily used. Overall, the spectrum utilization for the entire band is given as 15.2%. Also, Sikiru *et al.* (2017) investigated the effect that threshold is having on duty cycle within the GSM band in Nigeria and concluded that threshold of 5dB above noise floor level is more appropriate against the 10dB suggested by the ITU.

Palaios *et al.* (2013) conducted a survey in seven different cities of Europe covering a frequency range of 110-3000 MHz for two days. Results were presented in the form of duty circle tables for GSM 1800 and GSM 900 bands. In South Africa, Barnes *et al.* (2013) proposed a measurement system with the measurement period lasting for six weeks. Results indicate 20%, 40%, 92% occupancy rates for UHF, GSM 1800, GSM 900 downlink and downlink bands respectively. Additionally, in Nigeria Popoola *et al.*, (2017) studied the effect of pathloss models within the cellular band by collecting signal strength data in four routes. The research concluded that Standard Propagation Model gave the best fitness.

Martian *et al.* (2014) did a spectrum occupancy investigation in Romania. The range of frequency covered is 25 to 3400 MHz band. Results for spectral occupancy rates were presented for different threshold values. Spectrum occupancy rates were 14.19% and 21% in Maneciu village and Bucharest respectively.

In USA, spectrum survey was done in order to determine the spectrum usage by Subramaniam *et al.* (2015). The frequency range covered is 824-5800 MHz band. Results for average occupancy rates for certain bands were presented. Das and Das (2015) did a world-wide study of spectrum occupancy models. Chen and Oh (2015) did similar work. Chen *et al.* (2016) reported in detail the spectrum occupancy measurements on statistical scale and the spectrum prediction models.

Faruk *et al.* (2014) suggested a method of reuse of the TV frequency spectrum (i.e TV whitespace) by SU's band based on the results of field strength measurements carried out in Nigeria along six different routes. The results obtained shows that there is a strong correlation between terrain and frequency on protection distance. Furthermore, Faruk *et al.* (2015) developed a metric for estimation of reuse in TV band. Faruk *et al.* (2016) further did a wide band spectrum occupancy measurement covering frequency range from 50 MHz to 6 GHz while Babalola *et al.* (2015) conducted spectral occupancy measurement covering frequency range of 48.5 – 870 MHZ in Nigeria for both rural and urban locations. However, both works did not cover a major part of the FM band which is within the VHF band but rather covered only one FM transmitting station as against about four more FM transmitters operating in the environment. There is therefore need to scan and focus on a narrower band of the VHF which should also cover all FM transmitters. Adediran *et al.* (2015) worked on estimation of the proportion of UHF TV band in Nigeria. The work also compared the spectrum occupancy in Nigeria with those of UK and USA. This work did not consider the VHF band of the TV spectrum.

Table 1 shows the summary of previous work done in the area of spectrum measurement campaigns around the globe. From Table 1, it is clear that in Nigeria TV band has not received enough attention. Out of six papers reviewed in Nigeria, none specifically covered the VHF band. Paulson *et al.* (2017) only scanned through the VHF band. There is no specific work that focused on the VHF band despite the enormous attractive features of this band as described in section 3 below thereby, creating a gap for future work.

Table 1: Spectrum Occupancy Measurements across the World

S/NO	REFERENCE	COUNTRY	RESEARCH FREQUENCY RANGE (MHz)	DURATION	WHOLE BAND UTILISATION (%)	FM RADIO BAND (%) (UTILISATION)	VHF BAND (%)	UHF BAND (%)
1	Al-Hourani *et al.* (2015)	Australia	400 – 6000	3.8 Hours				
2	Si Xing *et al.* (2012)	China	20 – 3000	7 Days				
3	Dawei *et al.* (2009)	China	20 – 3000	7 Days				
4	Xue *et al.* (2013)	China	450 – 2700	24 Hours	13.5			
5	Yin *et al.* (2011)	China	20 – 3000	7 Days				
6	Pedraza *et al.* (2013)	Colombia	54 - 6000	48 Hours	78			
7	Hoyhtya *et al.* (2013)	Finland	2400 - 5000	24 Hours	23.36			
8	Hoyhtya *et al.* (2015)	Finland	2300 - 2400	2 Weeks				
9	Kokkoniemi & Lehtomaki (2012)	Finland	2450	1 Week				
10	Wellens *et al.* (2009)	Germany	20 - 6000	7 Days	32			
11	Wellens & Mahonen	Germany, Netherland	20 - 6000	6 Hours for 5 days				
12	Kone *et al.* (2012)	Germany, Netherland, Santa Barbara	20 - 6000	1 Week	26			
13	Patil *et al.* (2011)	India	700- 2700	48 Hours	6.62	-	-	0.4
14	Agarwan *et al.* (2016)	India	170 - 1000, 2400 - 2500	24 Hours for 7 days				
15	Garkal *et al.* (2018)	India	700 - 3000	2 Hours				

16	Patil *et al*. (2013)	India	174 - 806	24 Hours			3.55	7.22
17	Zennaro *et al.* (2013)	Italy	400 - 800					
18	Contreras *et al.* (2011)	Japan	90 - 3000	24 Hours	6.9		13.9	23.58
19	Dzulkifli *et al.* (2012)	Malaysia	30 - 3000	24 Hours for 2 days	11.29	71.2	59.8	32.7
20	Paulson *et al. (*2018*)*	Malaysia	80 - 2400	24 Hours				
21	Jayavalan *et al*. (2014)	Malaysia	0 - 3000	24 Hours			13.36	10.92
22	Ramirez *et al.* (2013)	Mexico	0 - 6000	24 Hours, 1 Week				
23	Aguilar *et al.*(2013)	Mexico	30 - 910	7 $^{1}/_{2}$ Hours				
24	Francisco & Pandharipande (2010)	Netherlands	2300 - 2600	24 Hours				
25	Chiang *et al.* (2007)	New Zealand	806 - 2750	20 - 30 Minutes over 12 weeks	6.21, 5.72			
26	Najashi *et al.* (2015)	Nigera	700 - 2400	12 Hours				
27	Paulson *et al.* (2017)	Nigeria	700 - 2500	1Day	4.73		26	
28	Najashi *et al.* (2013)	Nigeria	700 - 2500	12 Hours	6.62			
29	Babalola *et al.*(2015)	Nigeria	48.5 - 880	24 Hours				
30	Ayeni *et al.*(2016)	Nigeria	2400 - 2700	24 Hours	22.56			
31	Olunma *et al*. (2016)	Nigeria	240 - 960	24 Hours	7.9			
33	Ubom *et al.*(2019)	Nigeria	470-862, 174-230					43
34	Sikiru *et al.* (2017)	Nigeria	900, 1800					
35	Faruk *et al.*(2019)	Nigeria	900, 1800		10.55, 5.11			
36	Faruk *et al.*(2014)	Nigeria	UHF, VHF					
37	Faruk *et al.*(2015)	Nigeria	UHF					
38	Rasheed *et al*. (2015)	Pakistan	52 - 862	6 Days	17			
39	Pintol *et al*. (2016)	Philipines	54 - 800	2 Days	16		27	7
40	Qaraqe *et al.* (2009)	Qatar	700 - 3000	3 Days				
41	Islam (2008)	Singapore	80 - 5850	24 Hours over 12 week days	4.54	33	45	50
42	Barnes *et al.* (2013)	South Africa	50 - 3000	6 Weeks				20
43	Lopez Benitez *et al.* (2009)	Spain	75 - 7075	48 Hours	23	87	98	65
44	Pati *et al.* (2018)	Thailand	500 - 800					
45	Seflek and Yaldiz (2017)	Turkey	30 - 3000	15 Days	7.63	12.54	16.1	
46	Seflek and Yaldiz (2019)	Turkey	25 - 3000	6 Months	5.12	18.31	7.71	6.65
47	Ayugi *et al.*(2015)	Uganda		24 Hours				
48	Wang and Salous(2011)	U.K	100 - 2400	6 Days				60
49	Mehdawi *et al*. (2013)	U.K	180 - 230		11.02			
50	Harrold *et al*. (2011)	U.K	300 - 4900	6 Months				

51	Mehdawi *et al*. (2016)	U.K	0.009 - 2600	24 Hours				
52	Cheema and Salous (2016)	U.K	250 - 1000	24Hours				
53	McHenry *et al*. (2006)	U.S.A	30 - 3000	24 Hours for 2 days	17.4	-	40	51
54	Sanders (1998)	U.S.A	108 - 19700					
55	Otermat *et al.*(2016)	U.S.A	88.3 - 107.5					
56	Pagadarai and Wygliniski (2009)	U.S.A	88 - 1240, 1850 - 2686					
57	Vo Nguyen Quoc *et al.* (2011)	Vietnam	20 - 3000	4 Months	13.7	28	52	58
58	Valeta *et al.* (2010)	Czech Republic and France(Europe)	400 - 3000	24 Hours for 6 days				

3. ATTRACTIVE FEATURES OF TV BAND

The following are the interesting features of the TV band:

1. It has immense potential in parts of the geographical area which are very difficult and expensive to reach by optical fiber techniques and other types of technologies (Kimani and Langat 2017).
2. It is very applicable to developing countries where the telecommunications infrastructure is not yet in place. This can potentially serve as a cost effective way of making up for the unavailability of telecommunications infrastructure (Kimani and Langat 2017).
3. It has a good propagation state in both VHF and UHF sub-bands. IEEE 802.22 standard is very popular for remote communication and employs the CR technology. According to Liang *et al.* (2008) the standard ensures opportunistic use of the VHF/UHF in the TV bands. IEEE 802.22 standard does not need dedicated spectrum. This has led to decline in the expenses for deployment. The advantage of network coverage makes IEEE 802.22 technology appropriate for use in rural and remote places.
4. It is capable of ensuring wireless broadband access to both rural and large cities, with coverage within the range of 33 km to 100 km radius on the average (Liang *et al.*, 2008).
5. It is an attractive target for cognitive radio applications. It has a very good propagation and penetration characteristics and thereby improving communication quality and reduced energy consumption (Misilmani *et al*., 2016). TV white space interesting mainly because of its benefit of having a higher bandwidth and a larger coverage. In comparison with WiFi and 3G signals, a TV signal has a greater penetration capability particularly on buildings (Nekovee, 2009). Therefore, these bands are suitable for a large range of new emerging services (Cordeiro *et al*., 2006)
6. The short wavelength of TV signals makes it possible for small antennas to be used for signal reception. (Martin *et al*., 2008).
7. The advent of the Digital Switchover is expected to make available large portions of the UHF band. These portions will be available for use by the future telecommunication systems and equipment.

4. CONCLUSION

In Africa generally, the information on spectrum occupancy is still scanty and particularly in Nigeria. Not so much attention has been paid to the TV band and specifically the VHF band. Rather, previous surveys focused on a wide range of band. We therefore propose that future research should endeavor to address this identified research gap.

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