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# Technical and Economical Campaigns for Opportunistic Radio Spectrum Access For Efficient Radio Spectrum Utilization And National Development

## Popoola J. J.
Electrical and Electronics Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

**A B S T R A C T**

**Key words:**
Radio spectrum,
Spectrum holes,
Cognitive radio,
Traditional radio,
Cognitive capability

*This paper advocates for replacement of the current fixed allocation policy for the radio spectrum access and usage with opportunistic spectrum access (OSA) based on the imbalance the fixed allocation policy has created between radio spectrum scarcity and underutilization. In supporting the proposal, justification was made from technical and economical perspectives. From the technical point of view, it was practically demonstrated through radio spectrum occupancy measurements conducted that spectrum holes, which is the primary requirement for OSA is available in the nation's current licensed spectrum. Similarly, from the economic point of view, the paper makes it clear that if the use of the current fixed allocation policy for radio spectrum access and usage is contributing so much now to the gross domestic product (GDP) of nations despite its current disadvantages, there is potential of getting more from it if the access and usage of the radio spectrum can be replaced with OSA. Also, the results of the radio spectrum occupancy measurements conducted show clearly that the current fixed radio spectrum allocation policy is grossly inefficient with over 70% of the licensed spectrum unutilized in space, time and frequency. Based on this disadvantage, this paper advocates for the replacement of the current fixed radio spectrum allocation policy with flexible policy for both the efficient radio spectrum access and usage.*

## 1.     Introduction

The radio spectrum is the portion of the electromagnetic spectrum that ranges from 3 Hz to 3000 GHz. The electromagnetic waves in this frequency range (3 Hz-3000 GHz) called radio waves are widely used in wireless or radio communication. Radio spectrum is defined as a medium by which information is transferred wirelessly over distances ranging from a few metres to thousands of kilometres (ComReg-1650, 2016). Historically, the radio spectrum access and usage have been strictly regulated at both international and national levels in order to prevent interference among various users. At the international level, different portions of the radio spectrum are assigned by the International Telecommunication Union for different radio technologies, services and applications. Similarly, at the national level, the access and usage of radio spectrum is strictly regulated by laws. The laws require the radio spectrum users to pay in order to have exclusive right to certain portion of the radio spectrum. This

policy, known as fixed spectrum allocation policy, has served well in the past in preventing interference amongst the radio spectrum users and different applications (Popoola and van Olst, 2013).

However, in the last decade, as demand for the radio spectrum started to exceed the supply in some frequency bands, the traditional or fixed allocation policy to the radio spectrum access and usage has become problematic. One of the observed disadvantages of the traditional spectrum allocation policy is the possibility of the policy hindering radio spectrum availability for emerging future wireless services and applications since all available radio spectrum has been allocated. Another observed disadvantage of the policy is the imbalanced the policy has created between radio spectrum scarcity and radio spectrum underutilization as significant amounts of licensed radio spectrum are sporadically utilized by licensed users (Popoola and van Olst, 2011). This sporadic utilization of licensed spectrum encourages idleness of most allocated spectrum whenever the licensed owners or users are not transmitting, which is an indication of spectrum underutilization and inefficiency.

Correspondence:

E-mail address: jidejulius2001@gmail.com

This underutilization of radio spectrum is not limited to certain nations of the world or frequency ranges but cuts across all nations, developed and developing, as well as different frequency ranges (Popoola and van Olst, 2013). This is revealed by a series of actual radio spectrum occupancy measurements carried out by different researchers in different parts of the world at different frequency ranges. For instance, typical radio spectrum occupancy measurement conducted in 180–2700 MHz band in the urban area of Hull City, United Kingdom by Mehdawi *et al.* (2013) demonstrated that a significant amount of unused spectrum in these bands with an overall mean occupancy ratio as low as 11.04% over the whole band.

Similarly, in another radio spectrum utilization measurements that were conducted in Europe in the suburb of the city of Brno in the Czech Republic and in the suburb of Paris in France and the city of Paris in France in 400 MHz - 3 GHz band by Valenta *et al.* (2010) shows variations in radio spectrum usage in the three regions with overall spectrum utilization of 6.5%, 10.7% and 7.7% respectively.

Likewise, in Africa, some studies on radio spectrum occupancy measurement were conducted in countries like South Africa and Uganda to mention but a few. For instance, the spectrum occupancy measurements carried out by Barnes *et al.* (2013) in the Hatfield area of Pretoria, South Africa for UHF band, GSM 900 MHz and GSM 1800 MHz bands indicated variations in usage of the three bands with the UHF band has an occupancy of about 20% while those of GSM 900 MHz and GSM 1800 MHz bands are about 92% and 40% respectively. Similar study carried out in Kampala, the Uganda capital presented in Ayugi *et al.* (2015) using GSM900, GSM1800, the universal mobile telecommunications system 2100 (UMTS2100) and long term evolution 2600 (LTE2600) bands shows variations in those frequency bands considered.

The result of the study indicated an average occupancy rate of 8.8% and 52.4% respectively for both the uplink and downlink in GSM900 band while the corresponding values obtained for the uplink and downlink occupancy rate for GSM1800 band are 0.6% and 13.6% respectively. On the other hand, the obtained uplink and downlink occupancy results in the study for the UMTS2100 band are 0.56% and 48.7% respectively while the corresponding results for the LTE2600 band are 0% and 0.6% respectively.

These series of radio spectrum occupancy measurements show that scarcity of usable radio frequencies for wireless communications is not as a result of a lack of radio spectrum but because of the current inefficient fixed radio spectrum allocation policy.

Hence, as an alternative, a flexible access technology, which enables licensed spectrum to be used in an opportunistic

manner, can be introduced. The concept of opportunistic spectrum access (OSA), also known as dynamic spectrum access (DSA), is a de facto architecture which allows unlicensed or secondary user to opportunistically exploit the underutilized or unused licensed spectrum, also known as spectrum holes, by the licensed or primary user in an opportunistic manner. The enabling technology for OSA or DSA is cognitive radio (Haykin, 2005; Chang and Chen, 2010; Akyildiz *et al.*, 2009; Akyildiz *et al.*, 2008; Popoola and van Olst, 2010). Cognitive radio (CR), according to Popoola and van Olst (2013), is a radio system that adaptively and dynamically allows secondary users of the spectrum to opportunistic access the licensed spectrum by switching amongst spectrum holes at different time intervals. The radio system has the capability to operate in different spectrum bands unlike the conventional or traditional radio which operate only in a designated spectrum band due to regulatory restrictions.

This is because CR can sense its wireless environment to detect spectrum holes (Akyildiz *et al.*, 2008; Haykin, 2005; Chen *et al.*, 2008). Hence, according to Giweli *et al.* (2015), the operation of CR relies on spectrum holes availability. Thus, this research work is aiming at supporting OSA using the technical and economical advantages of the technology over the current fixed spectrum allocation policy. This aim was achieved using both primary and secondary data. The primary data were obtained from actual spectrum occupancy measurement carried out in order to determine the availability of spectrum holes in the Nation's spectrum usage profile. The secondary data used were obtained from internet.

The data were used to buttress the economic contributions of OSA to some nations of the world. This paper is organized as follows. Section 2 presents brief review on CR. Section 3 gives detailed information on the materials and methods involved in carrying out this study. In Section 4, the primary and secondary data obtained in Section 3 were presented and discussed. Finally, Section 5 presents the concluding remarks in support of OSA based on technical and economical perspectives.

## 2. Brief Review on Cognitive Radio

The term CR, according to Prasad et al. (2008), was first proposed in 1999 by Joseph Mitola III and Gerald Q. Maguire, Jr. The term was used to describe intelligent radio that can autonomously make decisions using gathered information about radio frequency environment through model-based reasoning and can learn and plan according to its past experience. Thus, this type of intelligence requires this unconventional radio to be both self-aware and context-aware. Based on this quality, different authours define CR in different ways. For instance, Akyildiz et al. (2006) defines CR as a type of radio that can change its transmitter

parameters based on interaction with the environment in which it operates. Likewise, Haykin (2005) defines CR as an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming radio frequency stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind: (i) highly reliable communications whenever and wherever needed; and (ii) efficient utilization of the radio spectrum.

Based on Haykin (2005) definition, CR has been identified as a key enabling technology that enables next generation network to use the radio spectrum more efficiently in an opportunistic manner without any interference with the licensed or primary user (Wang and Liu, 2011). CR is able to operate in this opportunistic manner without interference with the primary user because it is equipped with both cognitive capability and reconfigurability (Haykin, 2005; Akyildiz et al., 2006). According to Akyildiz et al. (2006) and Wang and Liu (2011), cognitive capability is the ability of a radio technology to sense and gather information such as transmission frequency, power bandwidth and modulation from its surrounding radio environment. With this capability, CR user or device can detect or identify spectrum holes and select the appropriate operating parameters to use. On the other hand, reconfigurability denotes the ability of CR device to rapidly adopt the operational parameters according to sensed information so as to perform optimally. In addition, reconfigurability ability of CR enables it to transmit and receive on variety of frequencies, unlike traditional radio that uses fixed frequency, and uses different access technologies supported by its hardware design (Jondral, 2005). With the aid of this feature, CR can select and reconfigure the best frequency band as well as the most appropriate operating parameters for its operation.

In an OSA manner, the challenges of CR technology, according to Popoola and van Olst (2014), are how the CR device or secondary user can:

(I)    determine which frequency band is available and detect the presence of a primary user when the primary user is operating in a licensed band or detect the primary user re-appearing after the secondary user has commenced communication;

(ii)   select the appropriate available frequency band according to the spectrum characteristics and user quality of service requirements;

(iii)  coordinate access to the available frequency band with other users; and

(iv)   quickly vacate the frequency band when a primary user is detected. These four essential operations form a cognitive cycle and enhance CR CR adaptation to dynamic radio environment. The cycle is supported by the following functions:

(i) spectrum sensing and analysis;

(ii) spectrum management and sharing; and

(iii) spectrum allocation and sharing.

A typical CR cycle, as shown in Figure 1, includes spectrum holes detection, best frequency bands selection, spectrum access coordination with other spectrum users and frequency band vacation whenever the primary user reappears.

CR detects the spectrum hole or white space through spectrum sensing and analysis and utilizes the spectrum. When the primary user starts operation or reappears at the licensed spectrum, CR device detects the activity through sensing and stop operation in order not to generate harmful interference to the primary user. According to Akyildiz et al. (2006), after the detection of the unused spectrum or spectrum holes through sensing activity, spectrum management and handoff function of CR enables CR device or secondary user to choose the best frequency band and hop among multiple bands according to the time varying channel features in order to meet various quality of service requirement.

Basically, in OSA or DSA, spectrum resources can be share in three ways;

(i) with primary users,

(ii) with other secondary users and

(iii) with both primary and other secondary users.

Thus, a good spectrum allocation and sharing mechanism is important in order to achieve optimal spectrum usage efficiency. When multiple users are sharing spectrum resources in this way, their access needs to be coordinated in order to alleviate collisions and interference. The cognitive cycle supporting this function is known as spectrum allocation and sharing. Generally, since CR devices are able to sense, monitor and detect the surrounding radio frequency environment, OSA can increase spectrum efficiency as well as supporting higher bandwidth services since every unused portion of the radio spectrum will be maximally utilized.

## 3.    Materials and Methods

In this section, detailed information on materials and methods employed in carrying out this study are presented. The methodology involved in carrying out this study is divided into two stages. The first stage was centred on primary data collection. This was done by carrying out actual field spectrum occupancy measurement to ascertain the availability of spectrum holes in the nation's spectrum usage profile. The second stage was centred on secondary data collection for the study. The collected data at this
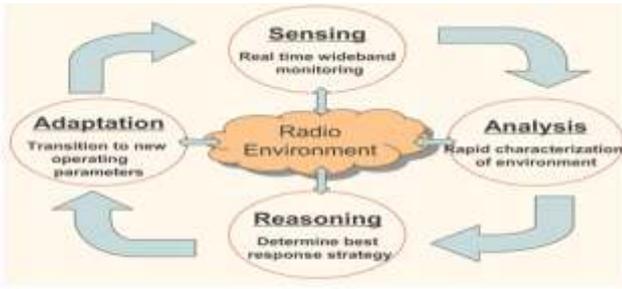
Figure 1: Cognitive cycle (Source: Wang and Liu, 2011)



Figure 2: Measurement setup

stage comprises of radio spectrum contribution to economy and gross domestic product (GDP) of some nations. Detailed activities involved in the two stages are presented in the next subsections.

*3.1     Primary Data Collection Stage*

     The measurement was conducted in an indoor environment in three selected cities in South-West geopolitical zone of Nigeria. The selected cities are Abeokuta, Ikeja and Osogbo, which are the state capitals of Ogun state, Lagos state and Osun state respectively. The choice of the geopolitical zone was based on its recognition as the true representative of the whole country based on its socio-economic development (Popoola et al., 2011).

     Likewise, the choice of the studied cities was based on the fact that devices and applications using all the frequency ranges considered are operating in the three cities. In carrying out the spectrum occupancy measurement campaigns, an Aaronia AG HF-6065 V4 spectrum analyzer with a frequency range of 10 MHz to 2.5 GHZ was used. The spectrum analyzer with its omni-directional AG HyperLOG 7060 antenna was connected to a laptop computer with "MCS" specially designed software to run Aaronia AG spectrum analyzer via a universal serial bus cable.

     The laptop served as both the scope and storage medium during the measurement. The measurement setup is as shown in Figure 2. The actual spectral occupancy measurements were conducted separately for a period of one week in each location with an interval of two hours in between sequence measurements. The

measurements data were collected from 80-2200 MHz for the three weeks. The frequency ranges, 80-2200 MHz, considered were sub-divided into eight sub-bands as shown in Table 1. In addition, the detailed information on the spectrum analyzer settings per each sub-band is also presented in Table 1.

     In determining signal presence in each sub-band, energy detection method was employed to determine the power spectral density (PSD) of each licensed users' signals in the considered frequency bands. This necessitates the determination of threshold value for each frequency band considered in the three locations. This is because when energy detection method is employed in radio spectrum occupancy measurements, it is the decision threshold value that is being used to classify a particular frequency band as either free or occupied. Thus, as reported in Popoola et al. (2016), correct setting of the decision threshold metric is important because high value of it will lead to under estimation of the channel occupancy estimation. On the other hand, if the decision threshold metric is low it will lead to over estimation of the channel occupancy estimation.

Table 1: Spectrum Analyzer Settings per Sub-band

| Frequency Band | Parameter | Value |
|---|---|---|
| Sub-band 1: (80 – 150 MHz) | Frequency Span | 70 MHz |
| | Bandwidth Filter/Video Filter | 200 kHz |
| | Timing | 500 ms |
| | Resolution | 51 samples |
| Sub-band 2: (150 - 400 MHz) | Frequency Span | 250 MHz |
| | Bandwidth Filter/Video Filter | 300 kHz |
| | Timing | 500 ms |
| | Resolution | 51 samples |
| Sub-band 3: (400 - 700 MHz) | Frequency Span | 560MHz |
| | Bandwidth Filter/Video Filter | 300 kHz |
| | Timing | 500 ms |
| | Resolution | 51 samples |
| Sub-band 4: (700 – 900 MHz) | Frequency Span | 300 MHz |
| | Bandwidth Filter/Video Filter | 300 kHz |
| | Timing | 500 ms |
| | Resolution | 51 samples |
| Sub-band 5: (900 – 1300 MHz) | Frequency Span | 400 MHz |
| | Bandwidth Filter/Video Filter | 300 kHz |
| | Timing | 500 ms |
| | Resolution | 51 samples |
| Sub-band 6: (1300 – 1700 MHz) | Frequency Span | 400 MHz |
| | Bandwidth Filter/Video Filter | 300 kHz |
| | Timing | 500 ms |
| | Resolution | 51 samples |
| Sub-band 7: (1700-1900 MHz) | Frequency Span | 200 MHz |
| | Bandwidth Filter/Video Filter | 300 kHz |
| | Timing | 500 ms |
| | Resolution | 51 samples |
| Sub-band 8: (1900 – 2200 MHz) | Frequency Span | 200 MHz |
| | Bandwidth Filter/Video Filter | 300 kHz |
| | Timing | 500 ms |
| | Resolution | 51 samples |

Hence, in determining the decision threshold values for each sub-band at each location, the average noise level was first determined by connecting a 50 ohm () resistor to the spectrum analyzer as recommended in Ayugi *et al*. (2015). The decision threshold was set by adding 3 dB to measured thermal noise. The decision threshold obtained varies from one frequency band to another due to variation in the noise level in each sub-band. The decision threshold values employed are presented in Table 2. The threshold values were used in estimating the actual spectrum occupancy for each sub-band by comparing the ratio between the points above the threshold to the total number of points during the measurement period. The actual spectrum occupancy (SO) is estimated using Popoola *et al* (2016) as;

$$SO = \frac{N_0}{N} \qquad (1)$$

where $N_0$ represents the total number of points above the threshold value and $N$ represents the total number of points during the measurement period. However, since average measured spectrum occupancy has the same meaning as duty cycle, which according to Jayavalan *et al*. (2014) is defined as the fraction of time the signal is present. Thus, equation (1) is re-expressed using duty cycle mathematical expression stated in Mehdawi *et al*. (2013) as:

$$Duty\ Cycle = \frac{nt}{m} \times 100\% \qquad (2)$$

where $n$ is the number of time slots $t$, where the received signal level is above the decision threshold and $m$ is the total number of time slots. Thus, equation (2) was used to calculate the average spectrum occupancy or duty cycle obtained per each sub-band. The average spectrum occupancy results obtained were presented in Section 4. Similarly, as a result of space, one typical actual spectrum occupancy profile pattern obtained for only one sub-band in the three locations was presented graphically to show the spectrum occupancy variations in both space and frequency.

*3.2      Secondary Data Collection Stage*

This stage, which is the second stage for data collection for this study, was carried out via internet survey. In this stage, relevant data on economic benefits of the radio spectrum usage to economy growth and GDP growth of some nations, including Nigeria were gathered. The obtained data, presented using Table and Figure, were also discussed in Section 4.

**4.          Results and Discussion**

Like Section 3, this section is divided into two subsections. In the first subsection, primary data obtained were presented and discussed to support the technical campaign for OSA

substitution for the current fixed spectrum allocation policy in the country. Similarly, in the second subsection, secondary data obtained were also presented and discussed to show the economical benefits of radio spectrum under the current fixed allocation policy, which has been judged ineffective and inefficient. The argument is that if these economic benefits are achieved under the current fixed allocation policy that has been judged ineffective and inefficient, it is certain that economic benefits, which will be derived with adoption of OSA, will be far more than the current benefits. Details on the results and discussion are presented in following subsections called technical and economical perspectives campaign for OSA policy.

*4.1      Technical Campaign for OSA Policy*

As stated earlier, availability of spectrum holes, which is unused portion of already licensed spectrum, is an indispensable requirement for OSA. Hence, before OSA policy can replace the current fixed allocation policy for radio spectrum access and usage, availability of spectrum holes must be ascertained. This necessitates the actual spectrum occupancy measurement carried out for this study. Field measurements for eight different frequency bands were conducted. However, only three of these frequency bands usage pattern for each location are presented because of limited space.

The results, as shown graphically in Figures 3-5, show that the current fixed radio spectrum allocation policy for spectrum access and management is grossly ineffective and inefficient with large portions of the frequency bands always lay fallows or unused most of the time. Critical observations of Figures 3-5 for each of the locations show gross inefficient of the current fixed spectrum allocation policy. The measurement results also show that the inefficient of the current fixed spectrum allocation policy is not limited to only one particular frequency or location but cut across all the frequency bands and locations.

Furthermore, the results as presented in Figures 3-5, also buttress the low percentage values of radio spectrum occupancy levels as earlier presented in work of Mehdawi *et al*. (2013) for Hull City, United Kingdom, Valenta *et al*. (2010)    in Paris, France, Lopez-Benitez *et al*. (2009) in Europe, Javavalan *et al*. (2014) in Malaysia and Ayeni *et al*. (2016) in Kwara State, Nigeria to mention but a few. The results shown in Figures 3-5, also reveal the availability of spectrum holes, which is an indispensable requirement for CR operation (Giweli *et al*., 2015). The implication is that adoption of OSA is feasible in Nigeria since there is availability of spectrum hole, which is the primary requirement for the opportunistic spectrum access technology. In addition, Figures 3-5 also reveals that usage of radio spectrum in this country, like other parts of the world; vary randomly in space, time and

frequency.

In addition, Figure 6 buttresses the fact that the current fixed radio spectrum allocation policy is grossly inefficient and must be replaced with flexible policy with the overall spectrum occupancy rate in all the three locations less than 30%. This result also reveals that over 70% of the allocated licensed spectrum in Nigeria is unutilized in space, time and frequency. The implication is that over 70% spectrum holes are currently wastes, which can be converted to wealth provided OSA policy has been adopted in this country. Furthermore, Figure 6 also shows it clearly that licensed radio spectrum utilization in Nigeria is urbanization dependent with Ikeja in Lagos state has the highest utilization level followed by Abeokuta, the Ogun state capital, and lastly by Osogbo, which is the capital of Osun state.

This result buttresses the finding reported in Lataief and Zhang (2009) that less than 35% of the licensed radio spectrum below 3 GHz is being utilized in even the most crowded areas of downtown of Washington in the United States of America. Since radio spectrum usage is relatively related to urbanization, this result implies that higher spectral holes are available in rural areas of this nation to support wireless services and applications, which can improve our national and socio-economic development. Based on the demerits of the current fixed spectrum allocation policy, as well as increase in demand for radio spectrum, coupled with the daily increase in deployment of new wireless services and applications in the recent years, it is obvious that fixed spectrum allocation policy is no more suitable for the increasingly dynamic nature of spectrum usage.
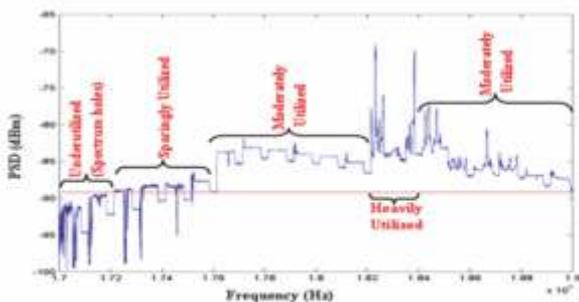
### 4.2    Economic Campaign for OSA Policy

Over the past few years, the use of radio spectrum has been identified as a major contributor to GDP and job creation in developed and developing nations of the world (Popoola and van Olst, 2014). For instance, the economic impact of the use of radio spectrum to the United Kingdom was estimated to increase from around £20.3 billion in 2000 to £24.7 billion in 2002 and £28.1 billion in 2006. Similarly, the use of radio spectrum has contributed immensely to some African nations' economy. For example, in 2007, it was discovered that the usage of radio spectrum boosted twenty-five African nations' GDP by over 5% while the GDP of another fourteen nations from the continent recorded GDP growth between 3% and 5% as a result of the use of radio spectrum (Popoola and van Olst, 2014). Furthermore, Table 3 shows the contribution of the use of radio spectrum to the GDP of some countries of the world in 2008. Figure 7 presents the percentage contribution of telecommunication to Nigeria GDP via the usage of the radio spectrum. The result shows annual progressive percentage contribution of the use of radio spectrum to GDP of Nigeria for over twelve years. This result buttresses the conclusion made in Minges (2016) that for every ten percentage point increase in broadband penetration, there are corresponding 2.14% and 0.32% respectively in GDP growth the use of the radio spectrum contributed to China and Panama and Philippines' economies. Thus, if the use of radio spectrum is contributing positively to nations' GDP in this way despite its current ineffectiveness and inefficiency usage in the current fixed allocation policy; it is obvious that under an effective and efficiency access policy its contribution will outperform the current performance. Based on these economic advantages of radio spectrum under this inefficient and ineffective policy, it is logical and reasonable that its access policy needs to be reformed in order to enhance its economical contribution and sustainability to our national as well as the world economic development.
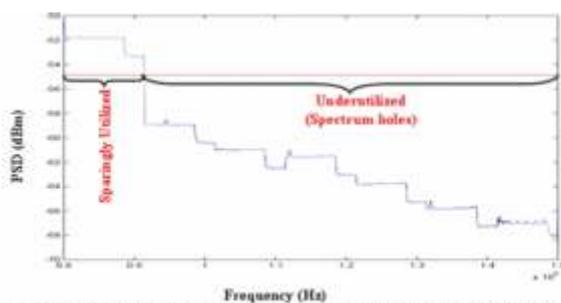


Figure 3: Actual Spectrum Occupancy for 80-150 MHz Frequency band for Abeokuta



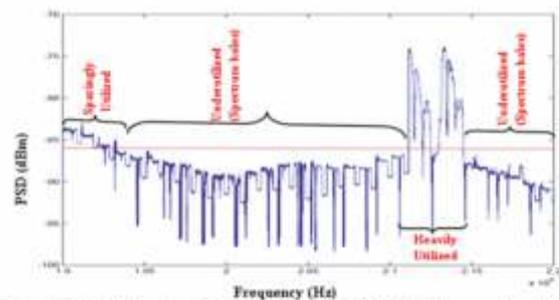Figure 4: Actual Spectrum Occupancy for 1700-1900 MHz Frequency band for Ikeja



Figure 5: Actual Spectrum Occupancy for 1900-2200 MHz Frequency band for Osogbo

Table 3: The Radio Spectrum Contribution to Some Nations'
Economy in 2008 (Source: Popoola and van Olst, 2014)

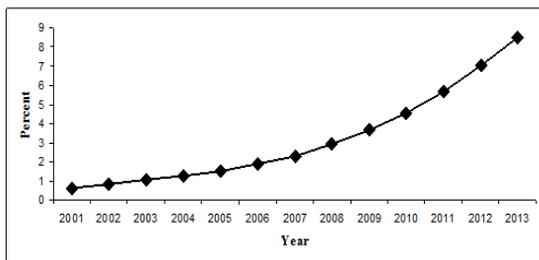| Country | GDP Contribution in 2008 |
|---|---|
| Malaysia | $26.5 billion |
| United States | $771.0 billion |
| UK | $39.9 billion |
| Ireland | $3.0 billion |
| Denmark | $3.2 billion |



Figure 7: Telecommunications contribution to Nigeria GDP (Adapted: Salisu and Ibrahim 2014)

## 4.  Conclusion

Without any doubt, the traditional or current policy of fixed radio spectrum allocation and access has served well in the past in preventing interference amongst the radio spectrum users and different applications. However, in the last decade, as demand for the radio spectrum started to exceed the supply in some frequency bands, the traditional approach to the radio spectrum access and usage has become problematic. One of the problems is the scarcity of radio spectrum the policy has created. In solving the problem, an alternate access to radio spectrum is proposed in this study. The proposal is supported from both technical and economical perspectives. The technical reason in campaigning for OSA as an alternate access policy in Nigeria, and the rest of the world, is based on availability of spectrum hole as a primary requirement for OSA. The results obtained from the spectrum occupancy measurements for this study as well as similar studies conducted by several researchers in different parts of the world, has shown it clearly that there is large portions of licensed spectrum that are currently underutilized that can be optimally utilized through OSA. Economically, it is observed that if the use of the radio spectrum is contributing so much now to GDP of nations, despite the inefficient way it is currently being used worldwide, there is potential of getting more from it if the access and usage of the radio spectrum can be reformed. Also, the results of the radio spectrum occupancy measurements conducted in this study show it clearly that the current fixed radio spectrum allocation policy is grossly inefficient with over 70% of the licensed spectrum underutilized. Thus, it is hereby recommended that the current fixed radio spectrum that has

been judged technically ineffective and inefficient be replaced with flexible policy for efficient radio spectrum access and usage.

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