Spectrum Survey and Coexistence Studies in the TV, WLAN, ISM and Radar Bands for Wireless Broadband Services

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Abstract- The proliferation of smartphones usage necessitates the increase of mobile data traffic volumes. Thus, Mobile Network Operators (MNOs) have to expand their network infrastructure in terms of coverage and capacity. However, the limited attributes of the electromagnetic spectrum, endlessly, pose challenges in meeting these demands. Recently, the International Telecommunication Union (ITU) identified TV (694-790 MHz), L-band (1.427-1.518 GHz) and lower part of C-band (3.4 -3.6 GHz) for possible mobile broadband services. In this paper, a comprehensive spectrum survey in the recommended bands is provided. Spectrum occupancy measurements were conducted at the dense urban areas of University of Ilorin, Kwara state, Nigeria. Energy Detection (ED) technique and Duty Cycle (DC) model were used for measurement evaluation analysis. Findings from this work revealed that Radar L band is fairly occupied with duty cycle of 17.19%. The C band is completely free and unoccupied by neither fixed satellite nor radar systems as only about 1% of the spectrum is presumably occupied. The occupancies in the Television (TV) and Industrial, Scientific and Medical (ISM) and Wireless Local Area Networks (WLAN), bands are 9.54% and 15.09% respectively. Findings show that huge amount of bandwidth is available for wireless broadband in the 2.4 GHz and C bands but not in the proposed TV and L bands.

Keywords: Spectrum Occupancy; Telecommunication Infrastructure; Radar band; TV band; Interference Studies

1. MOTIVATION

Global traffic of the mobile data is projected to increase by 57% from 2014 to 2019 [1]. This is driven by the increased in higher acceptance of data intensive devices such as smartphones. However, one of the major challenges that come with the explosive growth is that users also expect seamless mobile data connectivity, irrespective of their locations. In a progressively relaxed market, this has indulged the MNOs to expand their network infrastructure so as to meet customers' loyalty and remain competitive. The limited electromagnetic spectrum, endlessly pose serious challenges both from the regulatory and service providers' point of views. From the regulators' perspectives, the key desirable objective is ensuring flexibility in the spectrum usage and providing maximum interference protection to the licensed users. However, there is dichotomy between the spectrum usage and its allocation [2]. To this end, the craving for unlimited services with frequency spectral conservation, have prompted the regulators with no other option than to find a sophisticated technique to efficiently manage the spectrum resources. Unfortunately, connectivity in question is not limited to the provision of voice communications alone but also includes data transmission. With the recent advances in ICT, wireless telecommunications have transformed from leisure to necessity. Telecommunication has dominated all facets (education, health, business, etc.) of daily human life, making it the key to attaining the Sustainable Development Goals (SDGs). The Nigeria's population has increased to 182 million people as at 2016 population census with an annual growth rate of 3.5% according to the National Population Commission (NPC) [3]. The total number of GSM subscriptions has also exponentially increased from just over two million registered subscribers in 2002 to about 173 million in the end of 2018. Fig 1 shows the Nigeria subscriber data from the Nigerian Communications Commission (NCC) database [4]. The broadband penetration currently stood at 35.40% of both fixed and mobile service [4], a number considered low, aside the prevalent digital divide. The NCC has however released 30 MHz in the 2.3 GHz band, in the way, 2 X 70 MHz in the 2.6 GHz band in 2013 and 2016 respectively [5] [6]. This effort was to make more spectral spaces available for broadband internet penetration. Similarly, the ITU, during the World Radio-communication Conference (WRC-15) in 2015 [7], concluded its deliberations that revised the international treaty and the Radio Regulations, with the objective of making more spectral spaces available for mobile broadband services. The WRC-15 acknowledged 694-790 MHz frequency band, some frequency bands in the L-band (1427-1518 MHz) and the lower part of the C-band (3.4 -3.6 GHz) for mobile broadband used [8]. However, it was clearly mandated that the usage of these bands in the regions must not originate interference to other services. As such, studies related to the spectrum identification in these bands and coexistence with other services was included in the agenda for the WRC in 2019. Member states, particularly in Region 1, were encouraged to provide justification of using these bands. Therefore, in this paper, we provided a comprehensive spectrum survey in the recommended 694-790 MHz, L and C bands.

Fig 1: Nigeria Subscriber Data (Data Source, NCC: [4])

2. THE SUB 800 MHz (694-790) FREQUENCY BAND

In the last WRC-15 meeting, a major decision was taken to enhance the capacity in the 694-790 MHz band for mobile broadband services in ITU Region-1 (Africa, the Central Asia Middle East, and Europe,). Also, a worldwide coordinated solution was proposed for the enactment of the digital dividend. Decision made to assign 694-790 MHz band to mobile services and signifies same with International Mobile Telecommunication (IMT) in ITU Region-1 was concluded by the WRC-07 [9]. The said band was allocated to ITU Region-2 (The Americas) and Region-3 (Asia-Pacific). Protection right has been given to aeronautical radio navigation systems as well as to the television broadcasting that operates in this frequency band by allocating guard bands. Nevertheless, research on interference and coexistence studies within the band is still paramount.

3. THE ITU PROPOSAL OF RADAR BANDS

The ITU, at the WRC-15 in 2015 [10], proposed the revision of the international treaty and Radio Regulations by allocating Radar (3.4 -3.6 GHz) which forms the lower part of C-band and L-band (1427-1518 MHz) for mobile broadband usage [8]. Conventionally, radar bands are used for several purposes, including surveillance for defense and security, air traffic control, severe weather tracking, geophysical monitoring of Earth resources from space, and automotive safety. Standard radar types and their corresponding frequency of transmission are provided in [11]. Radar operation on some bands is either primary or secondary. Studies in [12][13] revealed that service such as 4G LTE produces out-of-band (OOB) emissions from secondary sources also compete for the radar band. This could significantly degrade radar system performance and subsequent decrease the maximum detection range. It is therefore; very clear that secondary operation on this band could be very challenging.

4. METHOD OF DATA COLLECTION

The set up used for the spectrum occupancy campaign comprises of an Omni directional antenna, a Global Positioning System (GPS), the Agilent Module N9342C spectrum analyzer with frequency range of 100 KHz to 7 GHz ad 32 GB storage device. The campaign were carried out at outdoor at the densely populated areas of the University of Ilorin, Kwara State, Nigeria (4^{o}38'47"E 8^{o}27'49"N). Spectrum utilization is evaluated based on the duty cycle (DC). Table 2 provides detailed information about the service bands that are covered in this study. Fig 2 provides the measurement framework.

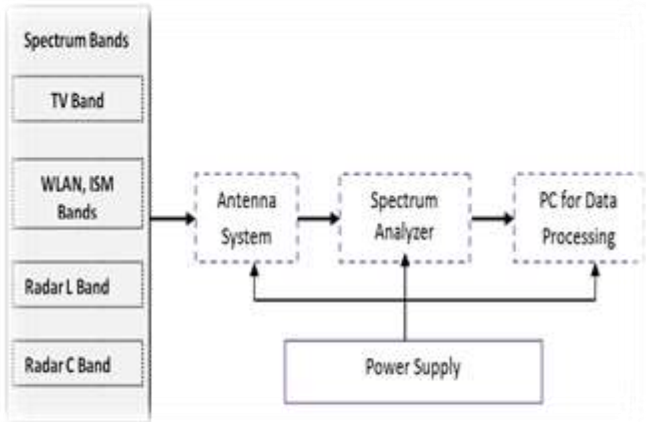

Fig. 2. Spectrum Occupancy Measurement Set-up

Table 2: Service Bands Considered

Service Bands	***Frequency range (MHz)***	***Bandwidth (MHz)***
TV Band	694-790	96
L Band	1427-1518	91
C-band	3400 -3600	200
WLAN, ISM	2300-2500	200

The spectrum usage data collected were stored in matrix form. In order to process the collected information, the received signal powers element were presented in the form of P ($t_{i,}$ f_i) (in dBm), in which f_i represents the frequency and t_i the time slot. Three steps were involved in the spectrum occupancy measurement evaluation process namely: inputting campaign data; append detection threshold; and computation of average duty cycle. The matrix, *Y*, of the datasets with the elements $P(t_i, f_j)$ defined by Equation (1).

$$Y(n) = \begin{pmatrix} P(t_1, f_1) & . & . & . & P(t_1, f_j) \\ . & . & . & . & . \\ . & . & . & . & . \\ . & .. & .. & . & . \\ P(t_i, f_1) & . & . & . & P(t_i, f_j) \end{pmatrix} \quad (1)$$

where *y(n)* is a matrix of received power at each point *n*. An energy detection (ED) [14] sensing technique was used as a sensing approach. A hypothesis is proposed such that the signal, $\{H_1\}$ is present, if and only if the threshold λ is less that the power detected. It is suggested as noise If it is not greater than the threshold, $\{H_0\}$. The threshold could either be set directly or estimated via Noise Floor (NF), which is the mean of the noise values. Despite the fact that the uncertainty about NF could be significant and also as a time dependent variant, it should be updated regularly. Mean measured noise of 5dB was used as the optimum in this study as suggested in [15-20].

5. Duty Cycle Model

The duty cycle was attained using the binary hypothesis as shown in Equation (2), the position of frequency band at a given location over period of time, x can be defined as an indicator function $1_D(x)$: $P(t_i, f_j) \rightarrow \{0, 1\}$ defined in [20]:

$$\Omega_D(t_i, f_j) = \begin{cases} 0, \text{ if } P(t_i, f_j) < \lambda_j \\ 1, \text{ if } P(t_i, f_j) \geq \lambda_j \end{cases} \quad (2)$$

Then, the duty cycle can be obtained by Equation (3).

$$\Psi_j = \frac{1}{N_t} \sum_{i=1}^{N_t} \Omega\ (t_i, f_j) \quad (3)$$

where Ψ_j represents the duty cycle and $\Omega\ (t_i, f_j)$ is a sample of power, when $P(t_i, f_j) > \lambda_j$. Ψ_j is determined for each frequency band.

6. RESULTS AND DISCUSSION

The measurement set-up in Fig. 2 was used to carry out the spectrum survey using the service bands in Table 2. Fifty (50) sample frames were collected for each band. Each frame has 461 time slots. The data frames were processed and duty cycle computed. Fig 3 show the Spectrogram for Radar L and C bands; Sub 800 MHz , WLAN and ISM bands.

In Fig 3 (a), a strong carrier was observed at 1.5 GHz frequency and other weak carriers spread within the band. The band is fairly occupied with weak signal between 1.42- 1.50 GHz and is 17.19% occupied (*see Table 3*). In Fig 3 (b) there was no indication of strong carrier signal within the band as the received signal strength measured varies between -101 dBm to -100 dBm. This may be considered to be noise. The 3.4-3.6 GHz band may be completely free as only about 1% of the spectrum is presumably occupied. It is apparently unoccupied by neither fixed satellite nor radar systems. Therefore, about 200 MHz bandwidth can be exploited for secondary transmission. The trace observed on the spectrogram is a background noise since there is no detectable strong carrier in the band. Fig 3 (c) shows the spectrogram and trace of the signals for sub 800 MHz band. The frequency under investigation spans from 694 to 790 MHz, covering a total bandwidth of 96 MHz. The frequencies of two major services were allocated within this band. These include the Personal Mobile Radio (PMR) that offers trunk radio services in the frequency range of 960-1429 MHz and the TV band 4 operating between 606-870 MHz. A total of seven carrier signals were seen, one of which is a wideband transmission. About 15.09% of the spectrum is occupied, freeing 81.5 MHz bandwidth. While, in Fig 4 (d) considerable activities were noticed on the WLAN and ISM bands. Spikes of carrier signals with varying degree of power levels were observed. About 9.54%

of the spectrum is occupied and the activities on this band were mostly the WLAN access points within the study location.

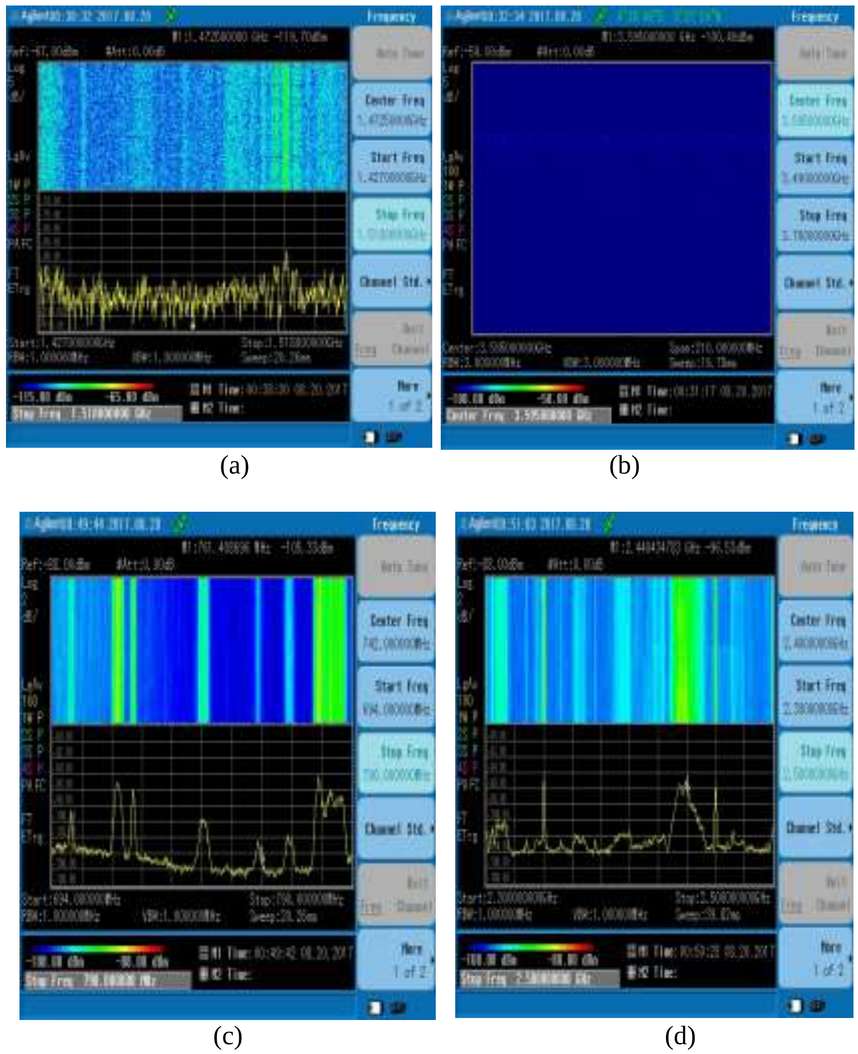

Fig 3. Spectrogram (a) Radar L band (b) Radar C band (c) Sub 800 MHz TV band (d) WLAN and ISM band.

TABLE 3: AVERAGE DUTY CYCLE

S/N	Start Frequency (GHz)	Stop Frequency (GHz)	Average Duty Cycle (%)
1	3.49	3.70	1.08
2	1.43	1.52	17.19
3	2.30	2.50	9.54
4	0.694	0.790	15.09

7. CONCLUSION

In order to justify the availability of TV, WLAN, ISM and radar bands for mobile broadband service deployment in Nigeria, an extensive spectrum survey and coexistence studies were conducted in these bands to facilitate decision making at the forthcoming WRC. Spectrum occupancy measurements were conducted at the dense urban areas of University of Ilorin, Kwara state, Nigeria. Availability of spectrum in each of the bands under study was detected based on Energy Detection (ED) technique and spectrum occupancy measurement was quantified using the duty cycle. The analysis of the measurements collected showed that Radar L band is fairly occupied with duty cycle of 17.19%. In contrast, C band is found to be unoccupied (only about 1% of the spectrum is presumably occupied) by neither the fixed satellite nor the radar systems. 15.09% of the TV band is occupied while the WLAN and ISM has 9.54% of being occupied. Therefore, a huge amount of bandwidth is available for the use of Long Term Evolution (LTE) wireless broadband in the 2.4 GHz and C bands but not in the TV and L bands. Hence, the spectrum campaign has proved the feasibility of reusing these bands for the deployment of broadband internet services in Nigeria.

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