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SUB- 6 GHZ 5G SPECTRUM FOR SATELLITE-CELLULAR CONVERGENCE BROADBAND INTERNET ACCESS IN NIGERIA

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Abstract – *Broadband access drives the global digital economy and has triggered the emergence of newer radio access technologies to meet data-driven consumers' expectations. In the period 2019-2025, it is estimated that the compound annual growth rate (CARG) of Sub-Sahara Africa will be above 28 % though ranked lowest amongst other regions. The Covid-19 pandemic has occasioned an unprecedented global demand for broadband internet access. Nigeria's broadband access is 42.02 %, which needs an advanced radio communication network infrastructure upgrade in order to bridge the current gap. Consequently, satellite-cellular convergence is a game-changer for increased rural and urban broadband connectivity penetration.*

The emergence of the fifth-generation (5G) network is expected to break new market share grounds and increase internet penetration. This paper focuses on the frequency range 1 (FR1: 450 – 7125 MHz) band due to their advantages, including broader coverage, better capacity, and low-cost deployment in sub-Saharan Africa.

This paper presents the current usage of Nigeria spectrum bands allocated for mobile communication in the sub-7 GHz band. Potential spectrum bands such as 450-470 MHz, 1427-1518 MHz, 2300-2400 MHz, 3600-4200 MHz, 4400-5000 MHz, 5480-5710 MHz 5900-7125 MHz are suggested to add to the already recommended bands due to their low utilization (i.e., below 10 % average duty cycle). In addition, it is suggested to deploy carrier aggregation methodology to meet gigabit speed for 5G in Nigeria. ***Copyright © 2009 Praise Worthy Prize S.r.l. - All rights reserved.***

Keywords:Fifth-Generation, Average Duty Cycle, Broadband Connection, Spectrum Occupancy

Nomenclature

3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
5G NR	Fifth Generation New Radio
CAPEX	Capital Expenditure
CARG	Compound Annual Growth Rate
CDMA	Code-division multiple access
COVID-19	Coronavirus Disease 2019
DL	Downlink
eMBB	Enhanced Mobile Broadband
FDD	Frequency Division Duplex
FL	Forward Link
FR1	Frequency Range 1
FR2	Frequency Range 2
FWA	Fixed Wireless Access
GEO	Geosynchronous Equatorial Orbit
GMT	Greenwich Mean Time
GSM	Global System for Mobile Communication
GIBAN	Global Internet Broadband Area Network
ISM	Industrial, scientific and medical
ITU	International Telecommunication Union
LEO	Low- Earth Orbit
LTE	Long Term Evolution
MEO	Medium Earth Orbit
MHz	Mega Hertz
mMTC	Massive Machine Type Communication
MNO	Mobile Network Operator
NCC	Nigeria Communication Commission
NFMC	National Frequency Management Council
PU	Primary User
RAN	Radio Access Network
RL	Reversed Link
SSS	Safety Security, and Surveillance
SU	Secondary User
TDD	Time Division Duplex
UMTS	Universal Mobile Telecommunication Services
UL	Uplink
URLLC	Ultra-Reliable and Low Latency Communication
WRC	World Radio Conference

List of Symbols

λ_j	Detection Threshold
t_i	Sample Time Frame
f_j	Frequency
x	Given Location
$\Psi(x,f,t)$	Duty Cycle
$\Omega_D(f_i,t_j)$	Sampled Power of a given frame
$\xi(x,f,t)$	White space

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H_1	Signal Present
H_0	Signal Absent
M	Total Observed Period
N	Number of Frame or Time Slots
$P(t_i,f_j)$	Received Signal Power
P_D	Probability of Detection
P_F	Probability of False Alarm
P_M	Probability of Miss Detection
P_R	Probability of receiving Signal Power
$Y_{i,j}$	Randomly chosen Signal power

I. Introduction

The global mobile network data traffic year-on-year has grown by 56 %, and it is expected that this trend will continue to grow due to the emergence of smart devices and demand for internet services [1]. By 2025, it is anticipated that the global mobile data traffic per month will be around 164 Exabytes (EB) compared to 33 EB at the end of 2019, as shown in Figure 1 [1]. The compound annual growth rate (CARG) outlook for Sub-Sahara Africa for 2019-2025 is expected to hit 28%, even though it is the lowest compared to other regions [1]. The above statement cannot be achieved without introducing a 5G network, which is projected to connect over 1.5 Billion devices by 2025, thus, amounting to almost one-third of the global population [2].

The aforementioned has driven mobile communication experts drawn from all industries to speed up work in increasing the deployment of 5G. Research work in effectively utilizing the spectrum band for a mobile communication system is among the hottest topics to meet the current demand of data-centric consumers.

The conceptualization of 5G communication system is becoming a reality after much work has been done of 3rd Generation Partnership Project (3GPP) releases 15 and 16, which fine-tune necessary steps in achieving the development and deployment of 5G communication system to meet up with the 5G use case [3], [4].

5G network is designed to be data-driven in order to provide super-fast data rate, ultra-low latency for real-time services such as videoconferencing, gaming, and ultra-high video streaming, ultra-reliable connection for critical services such as Tele-medicine, Fire service, Security service, and Manufacturing, ultra-low energy consumption for smart homes, smart cities, agriculture, and backward compatibility with heterogeneous networks [3], [4].

In [5], [6], it has been highlighted that almost 75% of the spectrum band below 7 GHz has been allocated to existing mobile technologies. However, the spectrum band below 7 GHz has been highly under-utilized from different spectrum occupancy measurements worldwide [6]-[9]. During the world radio conference held in 2015 (WRC-15), several spectrum bands were harvested from existing mobile services and non-mobile service networks (fixed satellite, aeronautical, and radio-location bands) [10], [11]. The spectrum bands suggested were sub-divided into three frequency ranges: sub 1 GHz band, 1-7 GHz, and above 7 GHz for 5G communication systems. However, it was agreed that the suggested spectrum bands should meet some specific criteria before deployment, which are global harmonization, wider bandwidth to cater for higher throughput, flexibility supports for a heterogeneous network, and backward compatibility with existing radio access technologies [10], [12], [13].

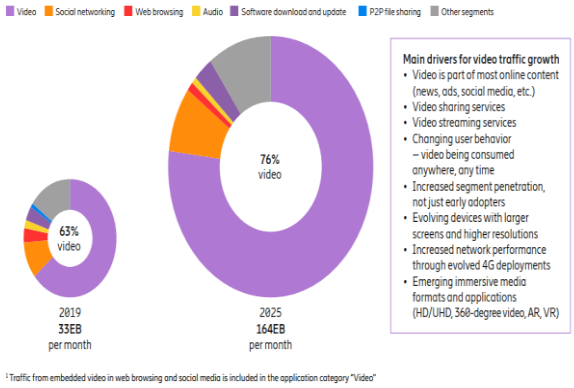

Fig. 1. Traffic from embedded video in web browsing and social media [1]

The suggestions mentioned above have been designed to meet the 5G new radio (5G NR) standardization, which have been done to provide capacity and coverage to support 5G use cases, such as the Enhanced Mobile Broadband (eMBB), Massive Machine Type Communication (mMTC), and Ultra-Reliable and Low Latency Communication (URLLC). For frequencies above the 7 GHz band, eMBB provides extremely high data rate users and applications over a low coverage area with at least 800 MHz bandwidth. On the other hand, medium frequency bands (i.e., between 1-7 GHz), eMBB, URLLC, and mMTC provide both coverage and capacity concurrently with at least 100 MHz bandwidth. Frequencies below 1 GHz offer broader coverage for mMTC, eMBB, and URLLC with at least 50 MHz [3],[4],[12]. 5G NR is designed to support fixed wireless access (FWA) networks and mobile communication networks. Studies show that spectrum bands needed for 5G will be in two-phase to affirm 3GPP Rel. 15, shown in Table I. This was concurrently supported by resolution 238 of the world radio conference in 2019 (WRC-19), which accepted 11 spectrum bands for above 7 GHz [3],[9],[13]-[16].

The FR1 or sub 7 GHz spectrum band has some unique characteristics, which are: guaranteed wide coverage for both outdoor and indoor, increased capacity, support up to 7 Gbps data rate, less susceptible to blockage and other environmental conditions, readily available equipment which requires low capital expenditure (CAPEX) and time [19],[20]. The first deployment of the 5G service was FWA, launched in October 2018 in the USA [2]. Since then, over 35 countries have deployed both FWA and mobile (millimeter-wave). South Africa

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has become the only country that has successfully deployed both technologies [2].

This study's motivation is to analyze spectrum usage of the mobile communication system in the sub-7 GHz band, and it shows the bands' ample potential in fast-tracking the deployment of 5G in developing countries such as Nigeria. No pilot study has been carried out within Nigeria in order to ascertain the efficacy of spectrum band usage of mobile communication services and their potential for 5G deployment. The contribution of this paper includes:

- Identifying potential candidate spectrum bands in the sub 7 GHz band for 5G deployment in Nigeria
- Determining suitable candidate spectrum bands for Fixed Wireless Access, thereby bridging the digital divide in Nigeria.

The rest of the paper is organized as follows. Section II discusses the background study of spectrum usage in the sub 7 GHz band, band allocation in Nigeria, and fixed wireless penetration, Section III discusses measurement setup and methodology, Section IV presents the results generated and the analysis.

TABLE I
5G SPECTRUM ALLOCATION BASED ON NEW RADIO [3] [12][14],[15],[17],[18]

Country	Frequency (GHz)	
	Frequency range 1 (FR1)	Frequency range 2 (FR2)
China	3.3 -3.6, 4.5 – 5	24.5 -27.5, 37.5-42.5
Finland	3.4-3.8	26.5-27.5
Japan	3.4-4.2, 4.4-4.9	27.5-29.5
Korea	3.4-3.7	26.5-29.5
Germany	0.7,3.4-3.8	26
Netherland	0.7,3.46-3.8	26
Italy	0.7,3.6-3.8	26.5-27.5
Canada	0.6	27.5-28.35,37-40,64-71
Sweden	0.47- 0.694/0.698	26
Europe	0.7,3.4-3.8,5.9-6.4	24.5-27.5
Australia	3.4-3.7	24.25-27.5,39
United Kingdom	0.7,3.4-3.8	26
United States	0.6,2.5,3.55-3.7,3.7-4.2,5.9-7.1	24.25-24.45 , 25.05- 25.25, 27.5-28.35, 37.0-40, 47.2, 64-71
WRC-15 &WRC-19	3.3-3.8,4.5-5,5.925-7.125	24.25-27.5,37.5-40.5,42.5-43.5,45.5-47,47.2-50.2,50.4-52.6,66-76,81-86 (primary basis) 31.8-33.4,40.5-42.5 and 47.47.2 (secondary basis)

II. Related Works

II.1. Global View

Fig. 2 shows the spectrum occupancy campaign conducted in different countries around the globe. The graphical representation shows that almost 75 % of the sub 7 GHz spectrum has been allocated to various services such as radio service, fixed wireless service, Wi-Fi, radar, aeronautical service, and mobile services. However, when spectrum allocation is juxtaposed with practical usage or utilization of the spectrum, as shown in Fig. 2, the sub 7 GHz band is under-utilized. The aforementioned signifies the potentials that sub 7 GHz bands can provide in 5G deployment [6]-[9].

II.2. Spectrum Allocation of a Mobile Communication Network in Nigeria

Extraction from the national frequency allocation table produced by the National Frequency Management Council (NFMC) shown in Table II shows fixed-mobile frequencies assigned by NCC for mobile service usage in Nigeria [21]. At the same time, Table III shows the relationship of the proposed frequency band usage in Region 3 (i.e., Nigeria, inclusive[1]). It is seen that though the frequencies are allocated for a particular service band, a number of them are in use or partially in use [21].

II.3. Broadband Access

Broadband penetration as of 2012 in Nigeria was estimated to be 6 %, with a maximum download speed of 1.5 Mbps for both mobile and fixed broadband and an internet penetration of almost 22 % when compared to July 2020, which stands at about 42.02 % broadband penetration and 32 % internet penetration respectively [22],[23]. 3G networks provided almost 80 % coverage of broadband access in Nigeria, out of which 90 % of the internet connection are in the urban areas [23]. Factors that impact the slow pace of broadband penetration in Nigeria are due to high capital expenditure (CAPEX), which includes high cost and inconsistent right of way, poor urban planning, frequent vandalism on fiber optics cable due to construction works, insecurity, and lip services attitude by regulators. In [24], the reduction of fiber cables and terminals cost has been highlighted. However, the right of way and labor cost stands at 80 % of the CAPEX.

The broadband connection could be through wireless mobile or fixed wireless access or satellite links. Table IV shows the advantages and the limitations of a broadband connection.

The integration of space and terrestrial communications segments [25]-[29] has revolutionized the current information and data exchange worldwide. The worldwide trend is increasing the need to establish real-time broadband communication systems and networks between the space and the ground station for data exchange. The above would provide deterministic dynamic spectrum access [30]-[32] to the remote and rural dwellers' information super-highway. The key challenges facing the developing nations include, but are not limited to, seamless and ubiquitous broadband connectivity and environment situational awareness (ESA) [27],[31].

The space-Earth link infrastructure [32], [33] can also be adapted and deployed using advanced connectivity technologies (such as beamforming [33]) for national safety, security, and surveillance (SSS). A global internet

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broadband area network (GIBAN) model can utilize the emerging space applications and technologies to provide real-time information and data exchange solutions that are reliable, available, affordable, and sustainable for socio-economic growth and development at the grassroots in a progressing economy like Nigeria [26]-[28].

II.4. Satellite Access

With the emergence of the 5G deployment, satellite services are to be interconnected into the mobile infrastructure, which will enhance the global economy and improve global coverage [26]-[33]. Satellite stakeholders have embraced the challenges of space-enabled smart communities' requirements which has enabled collaborative research industries and academia, emergence of new technologies between international space entrants, to develop products offerings innovative services, and merge satellite and terrestrial networks [25], [26], [31].

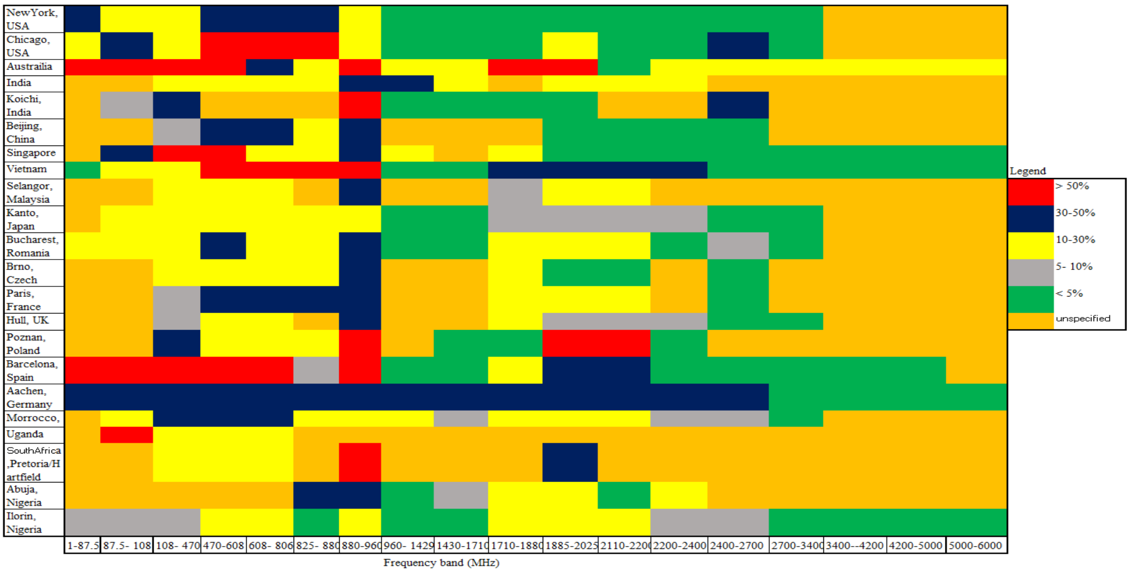

Fig. 2. Graphical representation of spectrum occupancy measurement carried out globally [6]

TABLE II
ALLOCATED NIGERIA MOBILE COMMUNICATION [21]

	By National Frequency Management Council			
	Nigeria Allocation	Nigeria Frequency (MHz)	NCC (MHz)	Nigeria Utilization
1	Fixed Mobile	450 - 470	450 - 470	CDMA (Private) (Currently Unused)
2	Fixed Mobile	811-821	790 - 824	TDD-CDMA [Now LTE 700MHz (703-748;758-803)MHz]
3	Fixed Mobile	824-849	825 - 835	FDD-CDMA RL ([Now LTE 800 MHz (832 - 875;791-821 MHz)]
4	Fixed Mobile	862-890	870 - 880	FDD-CDMA FL
5	Fixed Mobile	890 -915	880 - 915	GSM RL, LTE 900 UL
6	Fixed Mobile	935 - 960	925 - 960	GSM FL, LTE 900 DL
7	Fixed Mobile	1710 - 1785	1710 - 1785	GSM 1800 RL,LTE 1800 UL
8	Fixed Mobile	1805 - 1880	1805 - 1880	GSM 1800 FL, LTE 1800 DL
9	Fixed Mobile	1883-1910		FDD CDMA RL,
10	Fixed Mobile	1920-1960	1920-1960	3G FDD UMTS RL
11	Fixed Mobile	1963-1990		FDD- CDMA RL
12	Fixed Mobile	1990 -2150	1990 -2150	FDD UMTS RL with FDD UMTS FL(2110-2150)
13	Fixed Mobile	2150 -2180	2150 -2180	3G network (TDD)
14	Space operation / fixed mobile	2204 -2290	2204-2290	WiMAX, LTE
15	Fixed Mobile	2300-2400	2300-2400	4G LTE (Spectranent, Mobitel, BitFlux) OR LTE 2300 TDD OR BAND 40
16	Fixed Mobile	2400 – 2500	Unlicensed Band	ISM band
17	Fixed Mobile, Fixed Satellite	3400 -3600	3400 - 3518	4G LTE (3400 - 3518); Fixed Satellite (3540 - 3660)
18	Fixed Mobile	5650-5710	5480 - 5710	LTE
19	Fixed Mobile, Amateur, fixed satellite	5725-5875	Unlicensed Band	ISM band

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1 Band not captured are the LTE 700 MHz band, operated by GLO, and LTE 2600 MHz, which was awarded to MTN but were not in the latest frequency table.

TABLE III
UNUSED AND PARTIAL ALLOCATED SPECTRUM BANDS IN NIGERIA [21]

Frequency (MHz)	Current license applied in Nigeria	Region 3 Allocation
470 - 694	Allocated DVB-T	Broadcasting
1427-1518	Unallocated Fixed Mobile	Fixed Mobile
2700-2900	Allocated to Aviation	Radiolocation, aeronautical, radio navigation
3600-4200	Fixed Microwave and satellite communication (3700-4200 MHz)	Fixed satellite, Fixed Mobile, Aeronautical radio navigation
4400- 5000	Unallocated Fixed Mobile	Fixed Mobile
5900- 7000	Partly allocated for Fixed satellite (6200-6900) MHz; Cable TV relay, Long Haul P2P(5925-6425) MHz	Fixed and Fixed satellite

TABLE IV
ADVANTAGES AND LIMITATIONS OF BROADBAND CONNECTION

	Satellite Links	FWA	Mobile Broadband
Cost	Low CAPEX and OPEX, however deployment of satellite in space is huge	Low cost, leverage on the existing base station and fiber connection as backhaul	Very high CAPEX
Deployment	The best option for remote areas. In the case of coverage areas which has been affected by the disaster.	Easy to deploy in rural areas and remote areas. It has a very low latency when compared to mobile broadband and satellite link. It relies on microwave links and fiber-optic cable	Moderate latency compared to the satellite link, the area of coverage is more negligible when compared to FWA and satellite links.
Speed	Up to 156 Mbps	Up to 200 Mbps (dependent on backhaul link)	Up to 1 Gbps
Market	Backhauling link, remote tracking, aeronautical broadband, and emergency communication	Low complexity and cost make attractive in developed and developing countries	Readily available market.
Installation	Easy installation	Simple installation. Requires line of sight base station	Requires installation of a base station.

It is essential to investigate the existing and the emerging systems technologies, multifunctional network platforms and protocols, space segment assets, ground segment resources, and how they can be integrated and optimized to provide commercially cost-effective, sustainable, reliable, capability-based, and real-time services for future smart communities.

Developing a convergent satellite and 5G architecture provides new technologies for over-the-air integration using available satellite links (LEO, MEO, GEO). Since the 5G architecture is still using the 3GPP core network (Fig. 3), the satellite ground structure functions as a standard Radio Access Network (RAN), enabling the management of the satellite by the Mobile Network Operator (MNO), hence a multi-functionality between the satellite and mobile network.

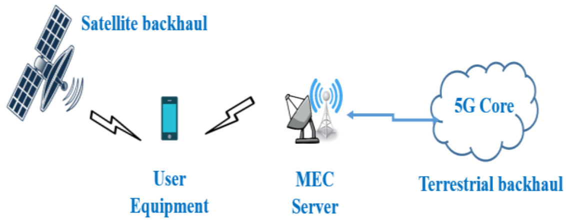

Fig. 3. Satellite-Cellular Convergence Architecture

Next-generation Satellite-terrestrial networks should retain massive applications in satellite networks and terrestrial networks as much as possible. It should handle services with varied functionalities in order to satisfy the requirement of 5G, which will involve spectrum sharing, multiple access, and resource allocation [34]. The satellite link should provide a path for information flow adequately distributed between the terrestrial and the satellite network [35]. An example of a satellite-terrestrial network is a broadband global network (BGAN), which offers cost-effective internet connectivity and phone services where cellular and wireless data networks do not currently exist [25], [26], [31].

An example of BGAN is Inmarsat, which consists of BGAN terminals connected to the satellites in orbit. BGAN has connection speeds above 650 kbps, which is dependent on the type of BGAN terminal deployed. BGAN is quite different from geostationary satellite communications systems, in the sense that they are easier to set up, require less complicated maintenance, lightweight terminals, and function in aeronautical and marine environments.

III. Methodology

III.1. Measurement Setup

Measurement has been taken in the University of Ilorin (UNILORIN), as shown in Fig. 4 using a handheld Agilent N9342C Spectrum Analyzer, which can measure between 100 Hz to 7 GHz, a data storage device that stores log files in .csv and .jpg from the spectrum analyzer, and Dell Laptop to process the measured data. The spectrum analyzer displays both

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the spectrogram and the trace signal of each frequency bandwidth measured. The energy detection technique has been implemented during post-processing, and 10 dB above the noise floor level has been used as threshold. As shown in Table V, measurement has been taken between 9 am-6 pm (9 hours) daily for each frequency band. Both the energy level and the spectrogram have been continuously stored in the USB storage device for the duration of the measurement. Twenty-six frames have been randomly selected at each hour for processing to calculate the duty cycle, as shown in (1)-(7).
Table V shows the geolocation of each base station with respect to the reference point (where the spectrum analyzer has been located) within the campus.

The data recorded by the analyzer have been the received signal power denoted by $P(t_i, f_j)$ (in dBm), where f_j is the desired frequency being measured, and t_i is the time slot. Each estimated frame within the dataset has 461-time slots (N) per frame, and 41,640 frames have been received into the analyzer per band at each hour. In [34], it has been showed that a minimum of ten frames is satisfactory to provide enough results during post-processing. Therefore, in the presented measurement, a random sample of twenty-six frames has been chosen at each hour in order to represent signal power Y, which is in matrix form (26, 461). 11986 signal powers are processed to evaluate the occupancy statistics per hour and 85888 to produce frequency-time occupancy plots per spectrum band.

$$\text{Power Sample} = \Omega(t_i, f_j) = \begin{cases} 0, & \text{if } P((t_i, f_j)) < \lambda_j \\ 1, & \text{if } P((t_i, f_j)) \geq \lambda_j \end{cases} \tag{1}$$

Where λ_j is the detection threshold, $P(t_i, f_j)$, is the received signal power. The sample's time frame t_i concerning f_j is considered in matrix Y, as shown in (2) and k is the total number of samples chosen from the raw data.

$$Y_{i,k} = \begin{pmatrix} t_{i,k} & \cdots & t_{i+1,k} \\ \vdots & \ddots & \vdots \\ t_{i,k+1} & \cdots & t_{i+1,k+1} \end{pmatrix} \tag{2}$$

The process of evaluating the occupancy statistics comprises three steps- raw data input, the setting of an adaptive threshold, and computing the average duty cycle of each channel, as shown in Fig. 5. Raw data inputs are received power levels at the antenna output that have not been processed. The adaptive threshold setting is done as each channel has different noise power. In order to minimize false alarms P_F or missed detection P_M, a detection threshold of 10 dB above noise floor is used as recommended by ITU in this experiment, as shown in (1), (3),(4), and (5):

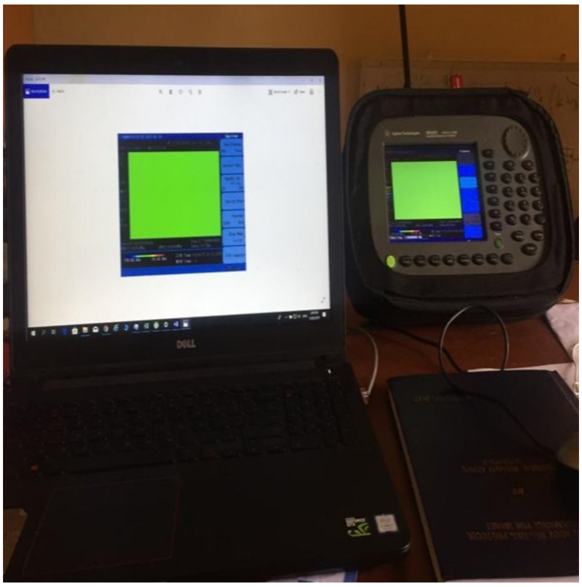

Fig. 4. Spectrum Periodogram Measurement Setup

$$P_D = P_R\left\{\text{decision} = H_1 | H_1\right\} \tag{3}$$

$$P_F = P_R\left\{\text{decision} = H_1 | H_0\right\} \tag{4}$$

$$P_M = P_R\left\{\text{decision} = H_0 | H_1\right\} \tag{5}$$

Though, [36] and previous studies have shown that 5 dB above the mean measure noise level can still provide optimum results. The average measured occupancy or Duty cycle, Ψ (x,*f*,*t*), indicates the percentage of time for a frequency band occupied over a given period, as shown in (6) [36].

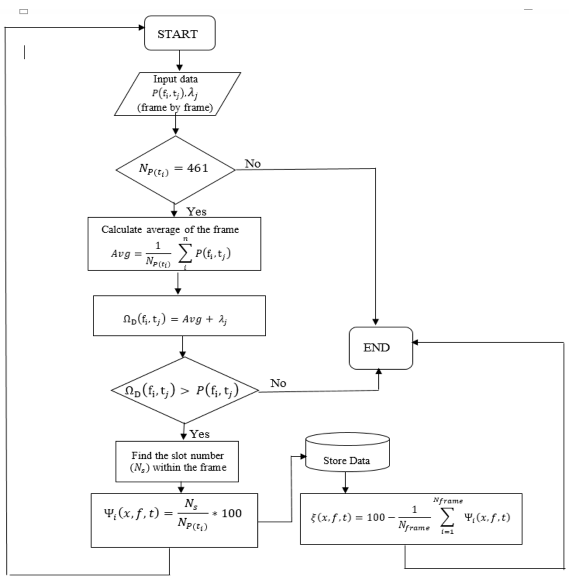

Fig. 5. Flowchart of Average Duty Cycle

$$\Psi(x, f, t) = \frac{1}{M} \sum_{N} \sum_{i=1}^{\tau} \Omega_D(f_i, t_j) \tag{6}$$

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Where $\Psi(x,f,t)$ represents the duty cycle for the specific frequency of a given location at a particular time, $\Omega_D(f_i,t_j)$ is the sample of power of a given frame, when $P(f_i,t_j) > \lambda_j$, M is the total observed period, τ is the signal duration, and N is the number of the frame. The white space $\xi(x,f,t)$ for band f, in any given location x, at a given time, t is evaluated as (7):

$$\xi(x,f,t) = 100 - \Psi(x,f,t) \tag{7}$$

III.2. Geographical Landmarks

Fig. 6 shows the geographical Satellite map of the University of Ilorin and the respective base station locations with reference points where the measurement has been taken. The university has 65,000 students offering different academic programs, including Undergraduate, Postgraduate, JUPEB, and Remedial, with an unlimited number of 4475 staff (Academic and Non-Academic) and about 1000 people that are either in the University for business or research purposes. Table V shows the base station location to their geolocations, distance to the reference point, service bands, and operating frequencies.

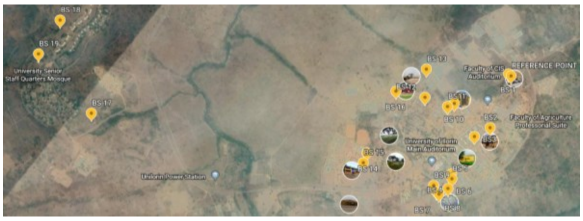

Fig. 6. Satellite View of Base Station Location within Unilorin Campus [39]

IV. Results and Analysis

Figs. 7-16 show the temporal variations of each mobile frequency range. On average, it has been observed that there has been a deep variation between 13:00-14:00 GMT and 15:00-16:00 GMT, which has been due to Muslim prayer time.

IV.1. Spectrum Analysis Based on Frequency Bands

Uplinks Frequencies

From Table II, uplink (UL) or forward link (FL) frequencies are 870-880 MHz, 880-915 MHz, 832-842 MHz, 1710-1785 MHz, and 2110-2150 MHz, respectively. In Figs. 7 and 8, the average duty cycle for 832-875 MHz, 870-880 MHz, 880-915 MHz, and 1710-1785 MHz has been 3.57 %, 2.85 %, 3.5 %, 0.68 % respectively. In Fig. 8, it has been shown that DTV shares part of CDMA UL (870-880 MHz), which indicates 2 DTV receivers have been ON at least within the range of 500 m. By observation, it has been shown that the uplink frequency average duty cycle has been below 5 %.

Downlinks Frequencies

Downlink frequencies or channels are congested due to the constant or continuous communication channels exchanging information and traffic signals simultaneously. Therefore it can be seen that GSM 900 DL, GSM 1800 DL, UMTS FDD DL, and LTE have shown a slightly higher average duty cycle, which has been 29.75 %, 21.61 %, 8.7 %, and 17.49 %, as LTE 900 (BAND 8), LTE 1800 (BAND 3), and LTE 800 (Band 20) respectively. Other LTE FDD bands such as 3400–3518 MHz and 5480–5710 MHz have an average duty cycle of 0.014 % and 0.38 %, indicating almost zero occupancies. However, LTE FDD is already being allocated to mobile operators by the books, but about 1748 (1518+230) MHz bandwidth is 99.5 % unused between 9:00-18:00 GMT.

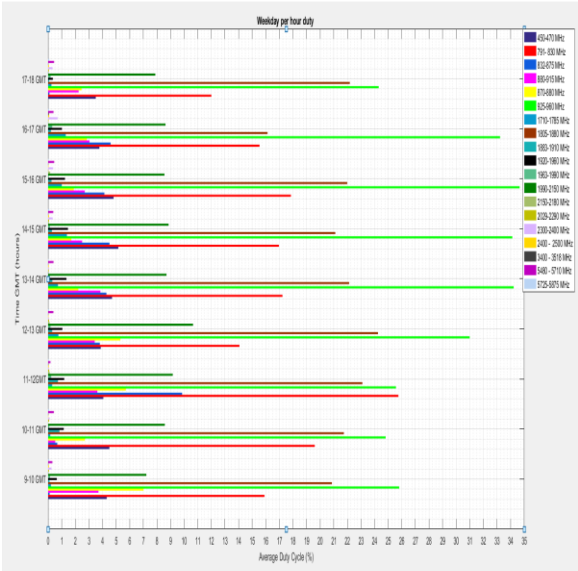

Fig. 7. An average duty cycle of each frequency band per hour

3G TDD/CDMA Frequencies

In Nigeria, almost or all CDMA operators have been either dead or acquired by GSM operators from statistics from NCC [40]. Due to some factors, including regionalization of spectrum allocation to CDMA operators, it is uncompetitive for them to compete with GSM operators, initial restriction of CDMA operators to fixed wireless, high interconnection rate, and other issues.

From Table II, 2300-2400 MHz and 2150-2180 MHz bands are allocated for 3G TDD. However, in Nigeria, 2300-2400 MHz bands are operating in regions, and 2150-2180 MHz bands are unallocated to any mobile operator. Likewise, 450-470 MHz band is allocated to private CDMA and DTV services.

The average duty cycle for 450-470 MHz, 2150-2180 MHz, 2029-2290 MHz and 2300-2400 MHz is

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4.3 %, 0.068 %, 0.058 % and 0.26 % respectively as shown in Figs. 7 and 8. Private CDMA (450-470 MHz) shows below 5 % duty cycle due to the presence of DTV within the distance of 500 meters. It is noted that in the early hours and lunchtime, and closing time (16:00 GMT), there is a decline in the average duty cycle showing a behavioral nature of usage. Fig. 8 shows that 3G TDD, WiMAX LTE are unused in these regions from the above explanation signifying less than 1% usage, which might be due to interference signals from other wireless technologies within the boundaries of the ISM band and UTMS band.

ISM Band

ISM bands consist of 2.4 GHz and 5 GHz respectively. Due to the locations of the outdoor access point (AP), the topography, and the building materials used within the faculty of CIS, the penetration power of received signals from the AP has been weak. All the AP has been in a non-line-of-sight (NLOS) to the reference point showing an average duty cycle of 0.051% and 0.067%, respectively. The nearest AP's minimum distance has been above 200 m to where the spectrum analyzer has been situated. All Wireless access points (WAP) have password for usage, or many students have exhausted their monthly data. It has been observed that most of the offices have been connected to the internet using LAN connection and laptops hotspots, respectively, which accounts for the low patronage of WAP due to its weak signal reception. Within the faculty, there are 6 Dual-band AP located at strategic positions. Another factor is that the penetration strength of the Wi-Fi signal is low, and the measurement has been taken indoors. Therefore, there is a high chance that the distance between the nearest AP has been far above 50 m.

Weekends and Hourly Variation

Measurement has been taken for three Saturdays, as shown in Table VI between 0.45-6 GHz band, and an average duty cycle of 6.02 %, 3.5 %, and 4.62 % has been recorded. The sharp decline in weekend 2 has been due to the public holiday that spread to the weekends. However, it has been observed that the average duty cycle for weekends had an irregular pattern, which has been influenced by the population of mobile users within the university. Figs. 9-16 show hourly variation from 9:00 GMT to 18:00 GMT, respectively. On each Figs. 9-16, it is shown that the frequency band 925-960 MHz has the highest average duty cycle per hour, followed by 1805-1885 MHz and 791-830 MHz, while the lowest average duty cycle has been 3400-3518 MHz, followed by 2029-2290MHz respectively.

The overall average busiest time of the day has been between 11:00-12:00 GMT, which has been 5.78 %, while the most active time has been between 16:00-17:00 GMT at 925-960 MHz band, which has been 34.66 % (Figs. 11 and 15). However, it has been found out that the mobile communication spectrum in Nigeria is significantly underutilized from the measurement taken.

Table V
GEOLOCATION OF BASE STATION IN UNIVERSITY OF ILORIN

BASE STATION NO	LOCATION	GPS LOCATION	OPERATION FREQUENCY MHz	SERVICE BAND	DISTANCE TO REFERENCE POINT (Km)
1	CIS FACULTY	8 29' 20" N,4 40' 27" E	2097	3G (UMTS)	0.04
2	NOC	8 29' 04"N, 4 40' 33" E	943	GSM 900	0.46
3	OPPOSITE BLOCK 8	8 28' 59" N,4 40' 31" E	943 & 1826	GSM900& GSM1800	0.63
4	LEGAL DEPARTMENT	8 28' 46" N,4 40' 33" E	2115	3G (UMTS)	1.07
5	COOPERATIVE BUILDING	8 28' 45" N,4 40' 34" E	958	GSM 900	1.11
6	GT BANK	8 28' 42" N,4 40' 35" E	943 , 2450	GSM 900 & ISM	1.21
7	FIRST BANK	8 28' 39" N,4 40' 34" E	2130	3G (UMTS)	1.29
8	UNION BANK	8 28' 39" N,4 40' 33" E	2115	3G (UMTS)	1.29
9	ZENITH BANK	8 28' 40" N,4 40' 31" E	2130	3G (UMTS)	1.25
10	BEHIND LIBRARY	8 29' 3" N, 4 40' 20" E	2115 &2130	3G (UMTS)	0.53
11	LAW	8 29' 01" N,4 40' 19" E	791	LTE	0.66
12	CLINIC	8 28' 59" N,4 40' 12" E	2145 &6847	3G(UMTS)& Relay Link	0.8
13	ARAFIMS HOSTEL	8 29' 06" N,4 40' 07" E	2663	Relay Link	0.78
14	BESIDE STADIUM 1	8 28' 35" N,4 40' 09" E	958	GSM 900	1.51
15	BESIDE STADIUM 2	8 28' 32" N,4 40' 10" E	6984	RELAY LINK	1.6
16	BUSINESS SCHOOL	8 28'55"N 4°40'04"E	2115 &2130	3G (UMTS)	1.04
17	SECONDARY SCHOOL	8 27' 52" N,4 38' 56" E	958	GSM 900	3.91
18	SENIOR STAFF QUARTERS 1	8 28' 08" N,4 38' 31" E	791	LTE	4.22
19	SENIOR STAFF QUARTERS 2	8 28' 00" N,4 38' 31" E	2145	3G (UMTS)	4.38

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FOOTNOTE: LTE: Long Term Evolution (LTE), Third Generation (3G), which can be UMTS or WCDMA, Global System Mobile (GSM), Industrial Scientific and Medical

Table VI
AVERAGE DUTY CYCLE OF ALL FREQUENCY BAND

Days (Hours)	Duty Cycle of all Frequency Bands (%)
Weekdays	4.99
Weekend 3	4.62
Weekend 2	3.5
Weekend 1	6.02

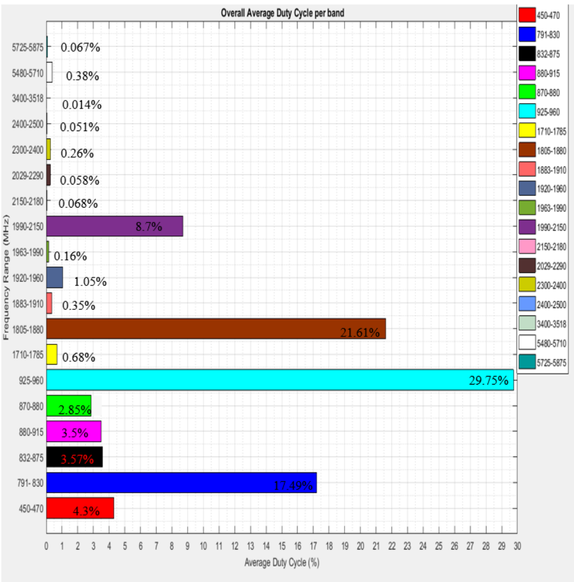

Fig. 8. Overall Average Duty Cycle per band

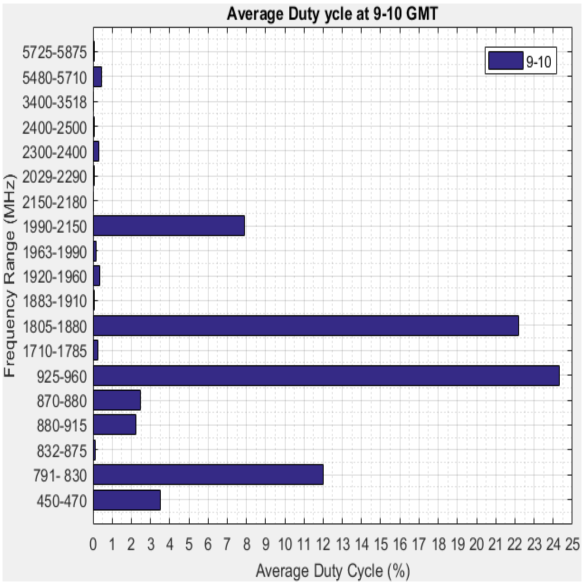

Fig. 9. Average Duty Cycle of Frequency bands between 9:00-10:00 GMT

Spectrum bands like 2029-2290 MHz, 2150-2180 MHz, and 3400-3518 MHz need to be put in use or re-allocated for 5G service in the future.

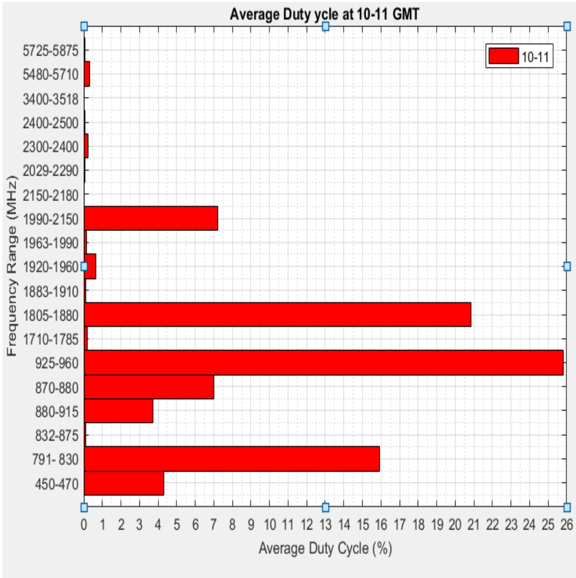

Fig. 10. Average Duty Cycle of Frequency bands between 10:00-11:00 GMT

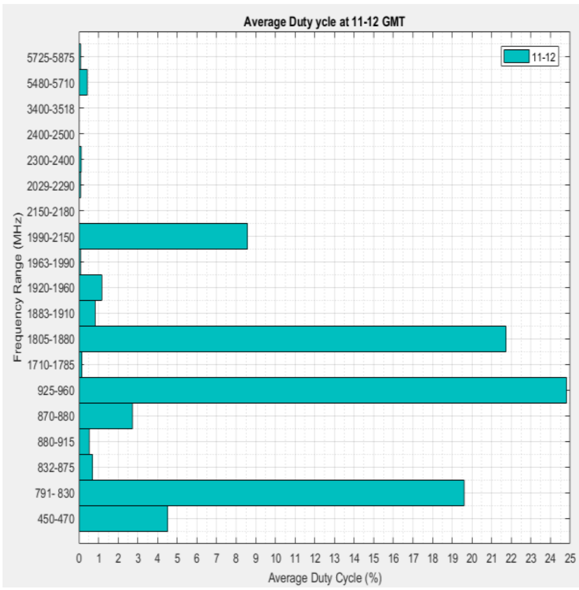

Fig. 11. Average Duty Cycle of Frequency bands between 11:00-12:00 GMT

V. Conclusion

The data presented in section IV have showed that the overall average duty cycle for both weekends and

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weekdays has been below 5 %. In addition, it has been discovered that UMTS and ISM bands have been below 10% utilization, which has indicated that mobile communication activities and internet penetration within the campus have been under-utilized.

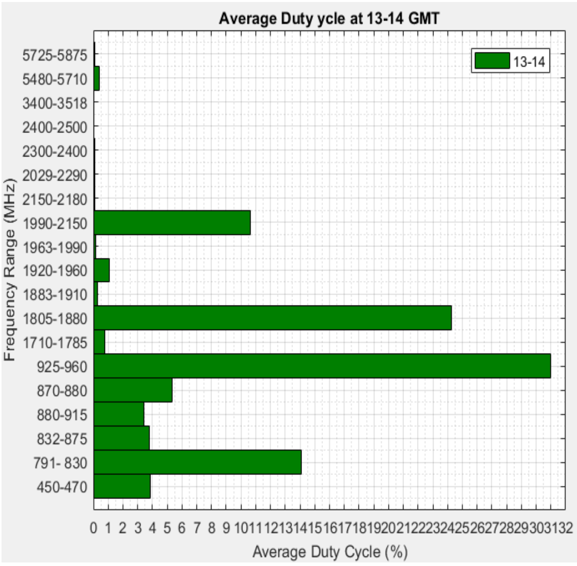

Fig. 12. Average Duty Cycle of Frequency bands between 12:00-13:00 GMT

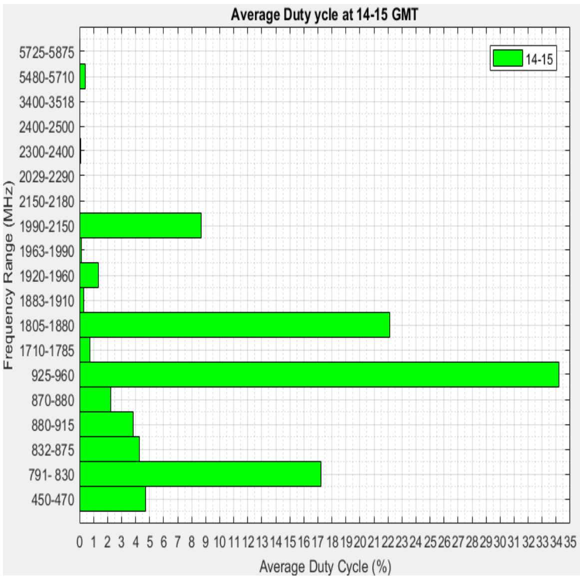

Fig. 13. Average Duty Cycle of Frequency bands between 13:00-14:00 GMT

The advantages of these low average duty cycles indicate that cognitive radio can be deployed or implement frequency re-farming and migration or clearance of frequency bands below 10 % duty cycle for 5G communication systems deployment.

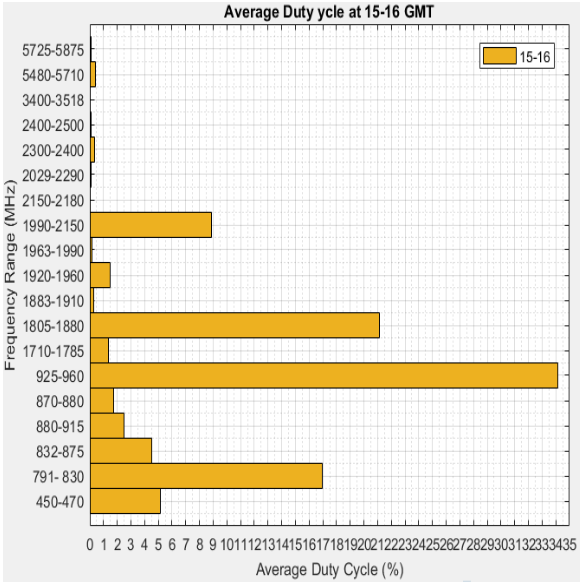

Fig. 14. Average Duty Cycle of Frequency bands between 15:00-16:00 GMT

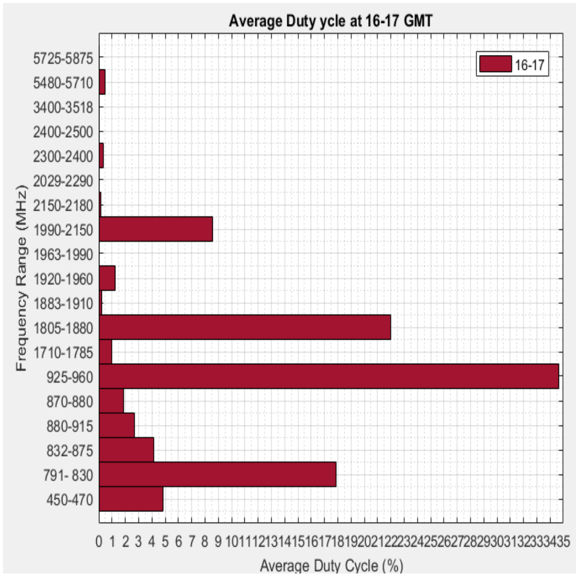

Fig. 15. Average Duty Cycle of Frequency bands between 16:00-17:00 GMT

Under 5G frequency bands, the sub-7 GHz bands cover the frequency range 1 (FR1), which is expected to drive coverage for the first deployment phase.

Frequency bands such as 450-470 MHz, 2300-2400 MHz, 5480-5710 MHz can be added to the already recommended bands such as 1427-1518 MHz, 3600-4200 MHz, 4400- 5000 MHz, 5900- 7000 MHz to increase bandwidth which is needed for gigabit speed in 5G. Likewise, uses cases such as massive machine type communication and ultra-reliable low latency communication system can massively leverage on sub 7 GHz band for deployment.

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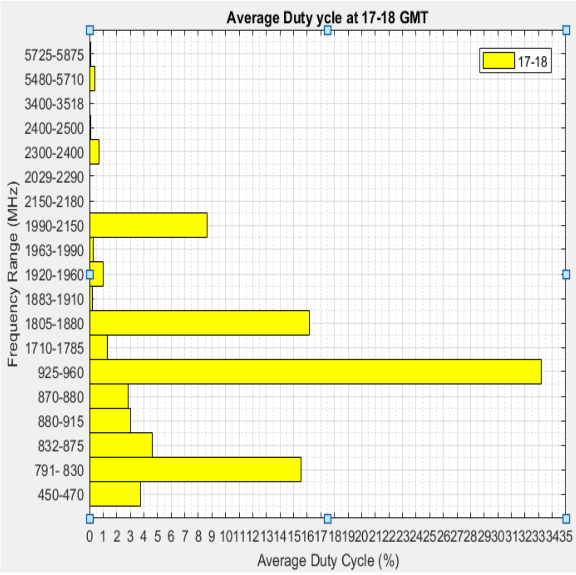

Fig. 16. Average Duty Cycle of Frequency bands between 17:00-18:00 GMT

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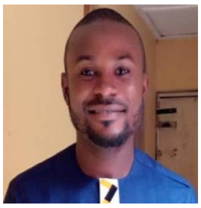

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